tendertips

Automated Asparagus Harvester Feasibility Study

Master of Engineering Management
ENMG 680: Project

Prepared By:
Andrew Lewis

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Disclaimer

This report has been prepared in partial fulfilment of the requirements for the degree of Master of Engineering Management at the University of Canterbury (UC). It is intended for use by The Tendertips Company (TTC).

A copy of the report will be submitted to UC and the report will be made available to TTC on the condition that the author, supervisor and the University will have any legal responsibility for statements or recommendations made therein. If TTC intends to rely solely on the contents of this report or to implement its recommendations it must do so solely in reliance on its own judgement.

Executive Summary

The Tendertips Company (TTC) is an asparagus growing a packing business which has a problem. Not enough New Zealanders are willing to manually harvest asparagus. Samoan workers are being employed through the recognised seasonal employer (RSE) scheme which incurs a large cost to TTC. This scheme is also susceptible to a change in government policy at any time.

Automated asparagus harvesters have been designed in the past however they inflict too much damage to asparagus plants and the paddocks in which they grow. Several research projects have also been undertaken to minimise this damage while robotically harvesting asparagus however no solutions currently exist.

In this project a low-cost system was designed and constructed to determine the feasibility of selectively harvesting asparagus without inflicting damage to asparagus plants or the paddock. The most technical component in this system was identified, accurately identifying and locating asparagus spears to be harvested.

A camera and lighting system, along with an asparagus data logging system was designed and tested, with the assumption that if this system succeeded, the development of an automated asparagus harvester would have a very high chance of success. The system proved that individual asparagus spears can be located accurately enough so as not to inflict damage on other spears during the harvesting process:

- 96.8% of asparagus spears were located.
- Average location error of 3.0mm.

The measurement of the size and height of asparagus spears was not very accurate due to the lighting system, however this is expected to be fixed with a design change.

A global positioning system (GPS) successfully saved the calculated size of the asparagus spear with its global location to allow for analysis of the asparagus paddocks using the Google Earth application.

The cost of robotically harvesting asparagus is forecast to be much less than manual harvesting:

- Manual harvesting cost $1.40 per kilogram
- Forecast robotic harvesting cost $0.41 per kilogram.

If one other investor was obtained to create a new business, which developed an automated asparagus harvester before harvesting asparagus in New Zealand and California, the forecast financials are:

- Net present value (NPV) of $1.613 million after ten years.
- Internal rate of return (IRR) of 33% after ten years.
- Maximum accumulated investment from TTC of $449,000 four years after development first begins.

The forecast income is through harvesting asparagus only as selling the machines or leasing the intellectual property is not viable.

A guiding document was created to guide TTC with the development of an automated asparagus harvester if it aligns with their business model.

The development of an automated harvester:

- Is technically viable.
- Will lower harvesting costs.
- Will ensure all of TTC's asparagus is harvested when required.
- Will return sustainable profits to the child business that TTC should create.

The project management techniques adopted in this project ensured the project was completed on the planned day of completion, while remaining on budget:

- Budgeted cost of work scheduled $24,478.21
- Budgeted cost of work performed $24,027.54

Contents

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- Beverly Hall, the administrator of the MEM programme at the University of Canterbury for ensuring the MEM course ticks along seamlessly.

1. Introduction

1.1. Company Background

The Tendertips Company (TTC) is an asparagus growing and packing business based in the Horowhenua, New Zealand. Their largest grower is Lewis Farms who currently has 80 hectares of harvestable asparagus. Countries with low labour rates are flooding the export market with low price asparagus, therefore TTC needs to increase their supply of high-quality asparagus, and minimise their unit costs to remain competitive.

1.2. Current Problem

Unfortunately not enough labour is available in New Zealand to the harvest the asparagus. Overseas workers are currently harvesting TTC's asparagus through the Recognised Seasonal Employer (RSE) scheme. The RSE scheme incurs additional costs through having to bring the workers to NZ from Samoa. This scheme may also cease to exist in the future if there was a change in government policy.

A small number of mechanical asparagus harvesters have been designed for green asparagus and these are in service throughout North America. While harvesting the asparagus spears these mechanical harvesters inflict a large amount of permanent collateral damage to neighbouring asparagus spears and the paddock, therefore no solutions currently exist that fulfil the requirements of TTC.

Before TTC invests a large amount of money in developing automated asparagus harvesters two major questions must be answered:

- Is it possible to efficiently harvest asparagus using automation while not damaging neighbouring plants or the surface of the paddock?
- How much money will be required to develop automated asparagus harvesters?

2. Background Research

At the beginning of the project the following questions were asked:

- Are there any existing solutions to the problem?
- Have similar projects been undertaken in the past?
- Can pieces of other technology be used to simplify the project?

2.1. Existing Solutions

There are two machines capable of mechanically harvesting asparagus, the Geiger Lund SP-2010 [1] and the Haws machine [2]. These machines cause a large amount of damage to:

- The asparagus spears being harvested.
- Asparagus spears neighbouring those being harvested.
- The paddock in which the asparagus is being harvested.

The Geiger Lund machine has tried ways to minimise collateral damage however nothing to date has proved successful [3]. TTC requires an automated asparagus harvester than does not damage any asparagus or the paddock; therefore neither of the currently available systems are suited to TTC.

2.2. Similar Projects

Projects related to increasing the efficiency of asparagus harvesting have been undertaken for a large number of years.

The Centre for Advanced Manufacturing and Industrial Automation at the University of Wollongong had designed a prototype selective asparagus harvester in 1992 [4]. In 1995 four different types of machines from the University of Wollongong were trialled in the USA [5]. No more information was available on these machines so it is assumed that it did not reach a commercially viable stage.

Another automated asparagus harvester project was undertaken in 2008 by the third largest asparagus producer in the USA due to high labour costs and low produce prices [6]. Due to a recent news articles outlining labour shortages in the same area it is unlikely that an automated asparagus harvester was developed after the completion of that project [7].

Nagasaki University completed a project in 2009 where asparagus was being harvested using three-dimensional (3D) sensors and a robotic arm [8]. This approach demonstrated that robotic arms are capable of harvesting asparagus once the 3D coordinates had been determined. However the method for determining the 3D coordinates was not feasible for TTC due to vastly different asparagus growing conditions.

2.3. Market Requirements

A survey was submitted to New Zealand asparagus growers in July 2012, to determine what they desired in an automated asparagus harvester. This survey received responses from six different asparagus growers however one grower was not suited for automated harvesting therefore his response was discarded as an outlier. The results from this survey indicated that New Zealand asparagus grower's desire the following features in an automated asparagus harvester, see table A.1 and figures A.2, A.3:

- The ability to store and recall data about the harvest, to indicate high and low producing areas of a paddock.
- The harvester should be able to harvest at least 95% of asparagus spears, with the sacrificed 5% or less acceptable in order for the harvester to travel slightly faster.
- Some growers would like the harvester to sort the harvested spears according to size, quality, and length, however other growers consider this unimportant.
- The harvester does not need to be autonomous; therefore a driver or operator controlling the harvester is acceptable.

Using these market requirements the final commercial asparagus harvester was better defined, which enabled strongly defined approaches to this project.

2.4. Background Research Summary

No automated asparagus harvesters that TTC could use to harvest their asparagus paddocks were found. Similar projects had been undertaken in the past however too much damage was inflicted on neighbouring plants and the asparagus paddock. No pieces of technology from other research projects could be used in this project either.

3. Project Approach

Before starting the project the different approaches to solving the defined problem were identified, with the best approach chosen.

3.1. Possible Project Approaches

Three different project approaches which could have been implemented were identified. Each of these approaches increased in complexity and cost, while improving the reliability of whether a commercial automated asparagus harvester should be developed. All three approaches assumed that a commercial asparagus harvester will have the following:

- Cameras to locate asparagus spears.
- A robotic arm to cut asparagus spears.
- A conveyor system to transport asparagus spears from the robotic arm to the storage crates.
- A storage area where asparagus spears are placed into storage crates.

The above assumptions were reached through knowledge of asparagus harvesting, knowledge of basic automated machines, and the design requirements identified from the survey.

A major component of an automated asparagus harvester is the software which detects the location of harvestable asparagus spears. One assumption that could be made is if asparagus spears can be located in camera images then the entire system will succeed. Images could be captured using a common digital camera, and software could be developed to detect asparagus spears within these images. This would result in:

- Short development time due to narrow project scope.
- Low development and equipment costs due to lack of complexity.
- Large uncertainty in technical success predictions due to a large number of assumptions.
- Large uncertainty in financial requirements due to an unknown system wide complexity.

The second approach was to design and develop a test rig that would be transported through an asparagus paddock locating asparagus spears and storing data about each spear. This system assumes that if the location of asparagus spears is detected, then a robotic arm or similar device will be able to cut the asparagus spear before it is stored. This would result in:

- Moderate development time due to moderate project scope.
- Relatively low development costs due to a low complexity.
- Low uncertainty in technical success predictions due to robust assumptions.
- Moderate uncertainty in financial requirements due to no design work regarding the harvesting and storing subsystem.

The third approach was to design and develop a complete proof of concept. This would be capable of detecting asparagus spears, cutting them at the appropriate level, and storing them in crates. This would result in:

- Large development time due to large project scope.

- Large development costs due to large amount of complexity.
- Low uncertainty in technical success predictions due to proof of concept results.
- Low uncertainty in financial requirements due to findings from proof of concept development.

3.2. Chosen Project Approach

The appropriate project approach was chosen using a weighted matrix. The weightings for each design consideration were based on the overall aim of the project, to determine if it is possible to robotically harvest asparagus and how much this would cost. Therefore the following weightings were given:

- Accuracy of predictions (technical and financial) – 5/5
- Cost of development – 3/5
- Required development time – 3/5

The most suitable approach was the second approach where a basic test rig would be designed and developed, see table 2. At this stage the basic test rig concept was developed, including all of the required components and materials.

	Weighting (/5)	Software Development Only	Basic Test Rig Developed	Functional Proof of Concept
Required Development Time		5	4	1
Weighted Required Development Time	*3*	***15***	*12*	*3*
Cost of Development		4	3	1
Weighted Cost of Development	*3*	***12***	*9*	*3*
Accuracy of Predictions (Technical & Financial)		2	4	5
Weighted Accuracy of Predictions	*5*	*10*	*20*	***25***
TOTAL		*37*	***41***	*31*

Table 2) A weighted matrix to determine the most suitable project approach, where 5 is most desirable and 1 is least desirable

3.3. Project Approach Summary

Three project approaches were identified, before the most suitable approach was chosen using a weighted matrix. The chosen approach would provide:

- A moderate development time.
- Moderately low development costs.
- Accurate technical predictions.
- Moderate financial predictions.

4. Initial Project Planning

This project was both very technical and specialised therefore strong project planning was required. The student also worked on the project alongside other commitments therefore the strong project planning made the project management easier throughout the project.

4.1. Project Steering Group

Geoff Lewis from TTC was the project director. Mr G. Lewis is an asparagus grower and processor with over thirty years of experience. Asparagus harvesting is a specialised area, therefore a person with strong industry knowledge was required. This ensured that the envisaged automated asparagus harvester was suitable for harvesting asparagus in New Zealand conditions without incurring unnecessary design iterations. Mr G. Lewis has previously been the project director for two different major technology based projects within TTC. Mr G. Lewis and was able to provide the following:

- Modifying the initial project scope based on asparagus knowledge and past project experience.
- Requesting project scope changes when they arose as this project progressed.
- Providing historical data relating to asparagus harvesting costs.
- Providing other information required to complete the financial tasks.

The student and project manager was Andrew Lewis. Mr A. Lewis has previously designed a computer vision system for a robotic fuel dispenser, and has a moderate understanding of asparagus. Therefore Mr A. Lewis undertook the following:

- Creating the initial scope for the project.
- Completing each of the required tasks within the project.
- Managing the project including: budget tracking, time tracking, and project reporting.

The project supervisor was Piet Beukman from the University of Canterbury. Mr Beukman has a large amount of experience with engineering, project management, commercialisation, and new venture start-ups which was all applicable to this project. Mr Beukman undertook the following:

- Overseeing the project to ensure it met the Master of Engineering Management degree requirements.
- Giving project management advice when necessary.

The technical supervisor was Patrick Lim from Industrial Research Limited (IRL). This project was very technical and included several different subsystems each of a different nature. Mr Lim has been part of the IRL team for twenty years, and is the robotics research team leader. This resulted in Mr Lim providing the following:

- Guidance for the technical tasks when necessary.
- Assurance to the project director that no large technological obstacles would prevent the project from reaching useful conclusions.

The diverse yet strong skill base of the project steering group was vital to the successful completion of this project. It ensured the appropriate guidance was available if the project lost its direction.

4.2. Tasks & Milestones

Technical Tasks and Milestones

The industry survey was very important in deciding what features the automated asparagus harvester test rig required. This resulted in a data logging system including a global positioning system (GPS) being required. Based on the student's prior engineering project experience a computer vision system with multiple cameras was the most accurate and cost effective method of locating the position of asparagus spears. The technical tasks and milestones were directly aligned with these requirements, see table A.4.

Financial Analysis Tasks and Milestones

Part of this project was to determine how much money will be required from TTC to develop an automated asparagus harvester. This depended on a range of factors including external investors, therefore the net present value (NPV) and internal rate of return (IRR) was required. To calculate the NPV and IRR a range of preliminary calculations and analyses were required, and the financial tasks and milestone were aligned with these, see table A.4.

Master of Engineering Management Requirements

In accordance with the Master of Engineering Management (MEM) course requirements a video presentation and final report was required, see table A.4. The tasks required to complete these milestones were the already planned technical and financial tasks therefore no further tasks were required.

4.3. Project Planning Summary

Because the project was both very technical and specialised, the project steering group was chosen using industry leaders. This resulted in the required information being available when necessary, and this information being reliable.

The project was broken down into tasks with corresponding milestones in order to monitor the success of individual design decisions, and give the project a strong direction.

5. Project Management

This project had a large number of milestones which ranged hugely in complexity and nature. Thorough project management was required to ensure the project remained on schedule, on budget, and scope creep controlled. This required planning at the start of the project, and constant monitoring.

5.1. Time Planning & Tracking

Time Planning

Before allocating time to individual tasks, two things were determined:

- The amount of available each week throughout the entire project.
- The complexity of each milestone.

Forward planning was required to determine how much time would be available each day, and how many days would be available each week. At various stages of the project the student performed work alongside the MEM course at Canterbury University, and alongside a full-time job. The time that would be available to work on the project during these different time periods was determined and allocated accordingly, see table 3. These weekly time allowances were allocated to the appropriate weeks throughout the entire duration of the project, see figure A.6.

Weekly Time Budget Assumptions		
Full-Time MEM	Weekday hours	7.5
	Weekend hours	8
	TOTAL	**15.5**
Full-Time Project	Weekday hours	40
	Weekend hours	7
	TOTAL	**47**
Full-Time Job	Weekday hours	2.5
	Weekend hours	4
	TOTAL	**6.5**

Table 3) The weekly time allocated to each time period

With the weekly time allowances determined the time to be allocated to each task could be determined. Because only one person was completing the tasks two important decisions were made with regards to project planning:

- No tasks were to be run in parallel, therefore only was task was in progress at any one time.
- Tasks would be allocated time allowances that involved whole days only.

Starting with the first scheduled task and finishing with the last scheduled task, time was allocated to each. The appropriate time for each task cannot be created without researching what work is required for each. If the project was to be rescheduled at a later date unplanned time would be incurred, and the risk of the project not finishing on time and on budget increased.

At the conclusion of the task time planning the overall project time required was known, therefore the project start date and an approximate project end date was determined.

Some tasks required the use of facilities such as a workshop to construct the test-rig or an asparagus paddock to test the entire system, therefore some tasks were rescheduled. While the student was away with full-time work it was appropriate for the financial tasks to be completed. The student could complete these tasks without requiring any other facilities. The tasks that were initially planned for this time period were rescheduled to begin immediately after the financial tasks had been completed. The time allocated to each financial task required minor modifications so two tasks would not be planned for the same day.

With each task having been allocated an appropriate length of time the overall duration known a project end date could be confirmed.

To summarise these time planning steps:

1. Determine how much time will be allocated to the project every week.
2. Allocate time to each project task in units of hours, but do not plan more than one task for an individual day. This starts with the first planned task and finishes with the last planned task.
3. Confirm the project start date.
4. Reschedule tasks if necessary based on what facilities will be required and when they will be available.
5. Confirm the project end date.

Time Tracking

Once the project was underway, with thorough project time planning the time tracking was much easier.

Several spread sheets were created to assist in project tracking, while giving the project steering group fast indications of the projects status. The following spread sheets were used for time tracking:

- Timesheet.
    - The timesheet stored the time spent on the project throughout the entire project and a short description of the work performed, see table A.8.
- Overall time tracking.
    - The overall time tracking spread sheet was linked to the timesheet, to allow automated monitoring of how the project was tracking overall, see table A.5. This information was plotted to give fast indications of the current project and future time requirements, see figure A.6.
- Task times tracking.
    - The task times tracking also used the data from the timesheet to monitor how much time had been spent on each task compared to what had been planned, see table A.9.
    - The budgeted and actual task times were added to the budgeted and actual material costs, to form the budgeted cost of work performed (BCWP) and scheduled (BCWS). This data was plotted to give a quick indication of the project status and task tracking, see figure A.10.

The overall project monitoring was not sufficient to determine whether the project was tracking on schedule, therefore later in the project another spread sheet and graph was created:

- Current task time tracking.
    - Every day's planned and actual time spent on a task was logged, see table A.11. This information was plotted to give an indication of how far the task has progressed, and what work is yet to be completed, see figure A.12.

Through having the spread sheets automated, the chance of human error was reduced and easier project tracking was achieved.

5.2. Budget Planning & Tracking

Budget Planning

The budget planning included two areas:

- Earned time value from the hours worked by the student.
- Material costs.

The earned time value planning was directly related to the time planning. Annual leave was assumed to not exist to simplify the calculation. The appropriate hourly rate for a graduate project engineer was calculated to be $27.88 per hour, see table 4.

Salary	$58,000
Weeks/year	52
Hours/week	40
Hourly rate	**$27.88**

Table 4) The hourly rate calculation for the students time

The material cost planning was performed for each task. Some materials were already present before the project started, others needed to be imported from overseas, and the remainder were sourced locally. The following rules were applied to the different scenarios:

- Materials present before the project.
    - These would be scheduled as being purchased in the first project week.
- Materials to be imported from overseas.
    - These would be scheduled as being ordered 5 weeks before they are required.
- Materials to be sourced locally.
    - These would be scheduled as being ordered 4 weeks before they are required.

The required components were already known from the chosen project approach stage. A price comparison was performed between sourcing each component locally and internationally. Components were planned to be sourced from the least expensive location while still being high quality components, and this information was logged, see table A.13. For imported components the price was calculated using the exchange rate at the time, and goods and services tax (GST) was not included as all of the items fell below the GST incurring threshold of NZ$400.

Budget Tracking

Several spread sheets were created to assist in budget tracking, while giving the project steering group fast indications of the projects status. The following spread sheets were used for budget tracking:

- Earned Time Value.
  - A table allowed for the students time value to be tracked, see table A.15. This was directly proportional to the number of hours completed, therefore the graph was incorporated into the time tracking graph, see figure A.6.
- Material Purchases.
  - Every purchase made was recorded, see figure A.14. Each of these purchases was assigned to an individual project task to calculate the BCWS and BCWP, see table A.9. The purchases made in any week were linked into the project material tracking spread sheet, see figure A.15.
- Project Material Tracking.
  - Any materials purchased needed to be assigned to a project week, see figure A.15. These values were retrieved from the material purchases spread sheet, and plotted to give fast indications of where the material costs were and what future costs were approaching, see figure A.6.

The budget tracking spread sheets were not as automated as the time tracking spread sheets, as more user input was required.

Overall Project Costs Tracking

The project earned time value and material costs were added to calculate the total project costs, see table A.16. This information was plotted to give an indication of how the project was tracking overall, see figure A.7.

5.3.Achieving Technical Outcomes

Task Completion Process

The technical tasks performed in this project were very diverse; however they were all completed with a similar approach, see figure 4. This approach assumed that every problem that had been defined could be solved. Within this approach the simplest solution was developed first. When this simplest solution did not solve the problem the area which was failing was improved. This cycle was repeated until the problem was solved, and the task completed.

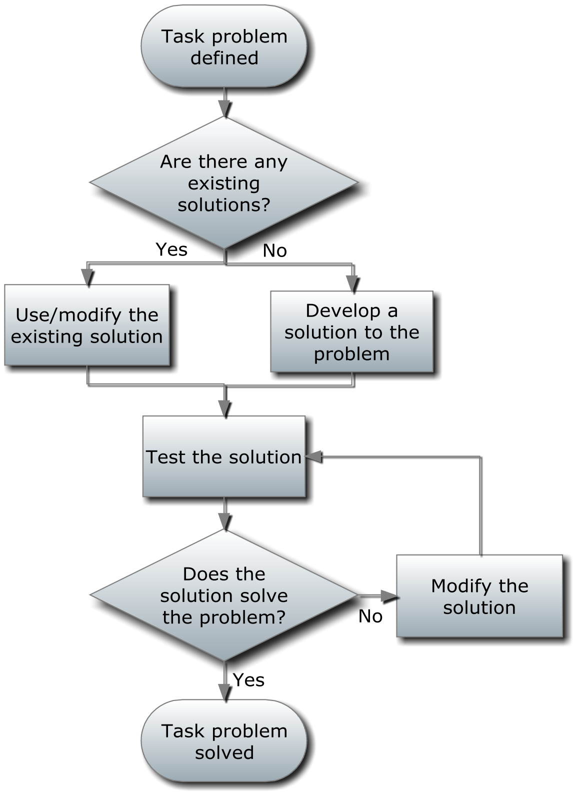

Figure 4) The technical task completion process

The described approach was most suitable for tasks which had a clear pass or fail criteria, such as reading the location of the asparagus harvester from a global positioning system (GPS). The location was either determined or it was not. When the location was not determined during development, the subtask which was failing was located and fixed.

More complex tasks without clear pass or fail criteria's required more iterations. An example of this is detecting asparagus spears in an image. A sequence of algorithms was used to manipulate the image and detect features. These algorithms had differing successes for different asparagus spears, sometimes missing the top or bottom of asparagus spears, as well as other images not detecting the asparagus spear at all. It was unlikely that every image would detect an asparagus spear perfectly, therefore a pass criteria of detecting a minimum of 95% of the asparagus spears was defined.

It was important to accept when a certain approach was not working, and make major modifications to the attempted solution. If inevitable major modifications were delayed it increased the chance of the project running over schedule and over budget.

Task Rescheduling

Several tasks required rescheduling over the course of the project. One example was an American supplier had forgotten to include a critical component in an order, resulting in a project task not being able to be completed before the scheduled completion date. The project required rescheduling, and once the component had arrived the task was completed.

When tasks required rescheduling it occurred as soon as it came to light. Rescheduling incurred lost time as the Gantt chart and project schedule both required rework. Delaying an inevitable reschedule would have incurred even more time, as the work completed while waiting for the component is likely to not have been as productive.

When rescheduling tasks it was sometimes better to integrate the remainder of one task into another. When a task did not have much work to be completed it was combined with a similar task to save time moving between tasks.

5.4. Project Reporting

Project reporting included creating and submitting fortnightly progress reports, milestone reports at the completion of each milestone, and progress reports when the project had been rescheduled. These reports were important for several reasons:

- Ensuring the project steering group knew where the project was, and where it was heading.
- Forcing the student to maintain records regarding the project tracking, project schedule, and budget status.
- Uncovering signs that the project may be diverting off the planned course.

Progress Reports

Progress reports were submitted two weeks after the completion of the most recent progress report or after the project had been rescheduled. These reports included information regarding:

- Current project status.
- Project progress.
- Project tracking.
- Project risk.
- Upcoming work.

A template was created for the first progress report and this template was used for the remaining eight progress reports, see appendix B for the final progress report. As the project progressed some pieces of information that the student decided were important were added to the progress report:

- The current project status table was modified to include the following pieces of information:
    - Work breakdown structure (WBS).
    - Task name.
    - Planned start date.
    - Planned finish date.
    - Planned duration (hours).
    - Actual start date.
    - Time spent to date (hours).
    - Current forecast completion date.
    - Actual completion date.
    - Actual time taken to complete (hours).
- Numerical budgeted and actual project cost comparisons for materials and overall budget.

The progress reports should have included a graph of the current project task tracking, however this was only implemented for the final milestone which had both begun and finished between adjacent progress reports, see figure 9 from Milestone 1.1.16 Report in appendix C for this project task tracking graph.

Milestone Reports

Milestone reports were submitted at the conclusion of each milestone, or when a milestone had been integrated into another. These reports included information regarding:

- Milestone summary.
- Milestone aim.
- Milestone process.
- Milestone budget.
- Milestone tracking.
- Milestone conclusions.
- Milestone success.

A template was created for the first milestone report, and used for the remaining eight milestone reports, see appendix C for all of the milestone reports. As the project progressed some extra pieces of information were added to the milestone report template:

- The milestone budget section was not present prior to milestone 1.1.8. This section outlined the budgeted and actual milestone cost including hours and materials.
- The milestone tracking section was only present for the final milestone report, 1.1.16. This section compared the time spent on the task each day to the budgeted time in a graph, see figure 9 from Milestone 1.1.16 Report in appendix C.

The time required to write a milestone was not incorporated into the milestone, instead it was part of the task named 'project management requirements' along with the progress reports. This time should have been incorporated into the corresponding milestone to simplify the project tracking.

The milestone reports were not submitted at the conclusion of each milestone. These reports sometimes took several days before they had been created and submitted to the required parties. These reports should have been created and submitted before the next task had started.

5.5. Project Management Summary

The project management implemented in this project performed well keeping the project on schedule and on budget. Numerous spread sheets were used to track all of the important data and information. Planning the timing for the project tasks and milestones provided reliable timings for the rest of the project:

1. Determine how much time will be allocated to the project every week.
2. Allocate time to each project task in units of hours, but do not plan more than one task for an individual day. This starts with the first planned task and finishes with the last planned task.
3. Confirm the project start date.

4. Reschedule tasks if necessary based on what facilities will be required and when they will be available.
5. Confirm the project end date.

The time tracking spread sheets provided adequate information to keep the project on schedule and tracking well:

- Timesheet.
- Overall time tracking.
- Task times tracking.
- Current task time tracking.

Tracking the budget of the project was easy using the following spread sheets:

- Earned Time Value.
- Material Purchases.
- Project Material Tracking.

Project tasks were rescheduled as soon as a change became known, which mitigated further project delays.

The fortnightly progress reports allowed the interested parties to remain connected with the project, and know how it was tracking. Information regarding the following areas was included in the progress reports:

- Current project status.
- Project progress.
- Project tracking.
- Project risk.
- Upcoming work.

After each milestone had been completed a milestone report was created. This closed each milestone with information regarding the following areas:

- Milestone summary.
- Milestone aim.
- Milestone process.
- Milestone budget.
- Milestone tracking.
- Milestone conclusions.
- Milestone success.

Without all of the mentioned project management tools and processes the probability of the project going over budget and over schedule would have been increased.

6. Results

The results from the project are very promising. The full-system testing provided strong evidence that a selective automated asparagus harvester is possible. The financial analysis demonstrated that automated asparagus harvesting will save TTC money and provide a sustainable return. The project management was executed well and kept the project both on budget and on schedule.

6.1. Technical

The designed and constructed test rig allowed thorough testing of the designed camera and data logging system. The rig was able to be pushed along asparagus rows, while the camera and lighting system was held firmly in place.

The infrared sensors proved suitable for detecting asparagus spears that the cameras need to check for harvesting. These did not take into account the height of the asparagus row between the wheels of the test rig, however this can be implemented in future designs.

The camera system performed well, proving that asparagus spears can be detected using LED lighting and cameras within an area free from external light. The cameras detected the location of asparagus spears to an accuracy where the asparagus spears could be harvested using a robotic arm. The length and size of asparagus spears was not very accurate, however improved lighting is expected to improve this accuracy, see table 5.

The GPS and software allowed the global location of asparagus spears to be saved with their size. The automatically generated Google Earth map file showing the location of asparagus spears with their corresponding size performed perfectly. The ability to save asparagus spears within a certain size range or within a certain percentile also performed perfectly.

Because the testing was performed once the majority of asparagus was in the fern state testing could not be performed under ideal conditions. Without a robotic arm it was impossible to test the accuracy of the location of an asparagus spear, therefore the separation of asparagus spears was tested. The average error between the spear separations using the cameras and using a ruler was 3.0mm and 3.07mm using two different settings. This error is likely to decrease with recommended changes to the system.

	Low Thresh	Mid Thresh	High Thresh
Overall Asparagus Detection Success	74.2%	80.6%	96.8%
Individual Asparagus Image Success	80.6%	91.7%	98.4%
Average Length Error (mm)	-8.5	-15.4	-18.4
Length Standard Deviation (mm)	13.2	14.5	13.3
Major Axis Error (mm)	-3.2	-3.8	-0.2
Major Axis Standard Deviation (mm)	4.0	3.6	22.2
Minor Axis Error (mm)	-4.2	-5.3	-5.8
Minor Axis Standard Deviation (mm)	1.9	1.8	1.7

Table 5) The results from the testing of the camera accuracy with asparagus lengths and heights

See milestone 1.1.16 report in appendix C for a full list of results from the system testing.

6.2. Financial Analysis

Automated asparagus harvesting is financially viable. Assuming half of the required capital is available from one other investor, the maximum accumulated investment is NZ$449,000 in the fourth year after development first begins, see table 6. Through harvesting asparagus in New Zealand and California this will return an accumulated NZ$4,835,000 to the development business after ten years, see table 7 and section 6.2 of the guiding document, appendix D.

The net present value (NPV) of this business will be NZ$1.613 ten years after first development, with an internal rate of return (IRR) of 33% at this same point in time, see section 6.4 of the guiding document, appendix D.

Required Funds per Investor										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Money ($000)	$133	$273	$422	$449	$399	$190	-	-	-	-

Table 6) The accumulated funds required by TTC each year after development of an automated asparagus harvester begins

Accumulated Cost Savings / Profit										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Money ($000)	-	-	-	-	-	-	$357	$1,388	$2,716	$4,340

Table 7) The accumulated financial savings or profit that the formed business will receive in the years following initiating the development of an automated asparagus harvester.

6.3. Guiding Document

TTC is not at a point where they are able to decide if they will develop and automated asparagus harvester. They need to analyse their own business model, and adjust this in light of the findings from this project. Because of this they are not in a position where they need a business model for a new business to develop an automated asparagus harvester. Instead a guiding document has been prepared. This guiding document outlines important information regarding the following:

- A market analysis of the current international and domestic asparagus industry.
- What the benefit to customers of automated asparagus harvesting is.
- Preliminary evidence of customer demand.
- What the required steps for developing an automated asparagus harvester are.
- Target markets.
- Project risks.
- Financial projections.
- Marketing and sales strategy.

See appendix D for the complete guiding document.

6.4. Project Management

The project management maintained that the project was completed on schedule and on budget.

- Budgeted project hours 779.5
- Actual project hours 763.1

The project required less hours than expected. This was only a small amount of time which did not affect the project schedule.

- Budgeted project materials $2,742.15
- Actual project materials $2,805.35

The project required more materials than budgeted. The cost of the extra materials was very insignificant so it did not affect the project in any way.

- Budgeted cost of work scheduled $24,478.21
- Actual cost of work performed $24,027.54

The overall cost of the project was less than expected. This was by a very small amount so again it is negligible.

- Forecast project completion 02/01/2013
- Actual project completion 02/01/2013

The project was completed on the expected completion date. This is because when components did not arrive on time, or the project scope changed the project was rescheduled quickly. By rescheduling the project quickly and planning the project thoroughly, changes did not affect the timing.

6.5. Results Summary

The designed camera and lighting system was able to locate up to 96.8% of asparagus spears and indicate their location to within an average of 3.0mm. The size and length of these asparagus spears was not accurate with the errors experienced directly proportional to the light settings within the software.

The financial analysis demonstrates that robotically harvested asparagus is much more economical than manual harvesting, and the NPV of the business which develops these harvesters is $1.613 million after 10 years with an IRR of 33%.

The project management techniques adopted for this project kept the project on budget and on schedule.

7. Conclusions

A successful business can be created to harvest asparagus for asparagus growers in New Zealand and California. There is a risk that an automated asparagus harvester will not perform as expected after development, however the large expected benefits outweigh this risk.

Asparagus can be selectively harvested without inflicting damage to the target asparagus spear, neighbouring asparagus spears, or the asparagus paddock. Damage-free automated asparagus harvesting has not been achieved before, therefore the development of a commercial version will require innovative thinking and a strong motivation. After an automated asparagus harvester has been developed there is potential to develop automated harvesters for other ground based crops. These ground based crops may have a different season to asparagus so the harvesters could be utilised in New Zealand for the majority of each year.

The current economic climate has now made the development of automated asparagus harvesters viable. A large monetary investment is required, however with the expected cost of harvesting asparagus dropping from $1.40 per kilogram to $0.41 per kilogram through automation the large investment is justified. After TTC's development it is likely that other asparagus growers may develop automated asparagus harvesters at a reduced development cost through implementing a similar design. TTC will need to perform regular upgrades to their automated harvesters to keep reducing the harvesting costs to remain competitive against competing asparagus growers with automation.

The multiple camera system with artificial lighting was a successful approach. The large amount of functionality which software introduces is likely to make the chosen method more accurate than the existing mechanical approaches which are not suitable in New Zealand. The capability within software coupled with the decreasing cost of technology is becoming better known. The machinery within horticulture is traditionally mechanically based; however more research and development projects are likely to be performed in this sector. As automation becomes more widely used, the levels of production will increase resulting in lower costs to consumers, and a healthier society through increased fruit and vegetable intake.

There has been a large amount of interest in this project. A business incubator has expressed interest in supporting a business start-up and obtaining investment for the continuation of this project. A technology development company has contacted TTC with regards to developing an automated asparagus harvester for TTC. The interest is because there is now a need for automated harvesting, where it did not exist to a great enough level earlier. This need is likely to increase for asparagus, and for other crops.

The number of jobs created through having more asparagus to process is not likely to exceed the number of jobs lost through automated harvesting. The harvester will ensure that the asparagus can be harvested economically; therefore TTC is more likely to stay in business and provide jobs to a number of people rather than no one. If TTC does not develop a harvester there is a risk that other asparagus growers develop automated harvesters and force TTC out of business, again providing jobs to no one. The reality is automation is becoming more important to businesses, and the population must up skill in order to be employable. If the population does not up skill at a fast enough rate, the separation between the high and low income earners within New Zealand is going to increase.

8. Recommendations

TTC should develop an automated asparagus harvester as soon as possible. In six years there will be an accumulated cost saving while guaranteeing that TTC is capable of harvesting all of their planted asparagus.

8.1. Technical

With the next development stage of an automated asparagus harvester the following changes should be made to the camera and lighting system:

- At least four cameras in the camera system.
  - This will allow multiple asparagus spears to be detected when at least one is positioned behind another.
- Several rows of narrow-angle LED are arranged in a fan.
  - The wide-angle LEDs illuminated the ground too much, and the single row of narrow-angle LEDs did not illuminate enough of the area under the test rig. By having several rows of narrow-angle LEDs the asparagus spears will be easier to locate with a much higher accuracy when determining both the height and size of asparagus spears.

If the calculated size of asparagus spears becomes more accurate a real-time kinematic (RTK) GPS system should replace the standard GPS system. This would allow the precise location of each asparagus spear to be saved along with the size of asparagus spear for later analysis. From this data the top producing asparagus spears can be identified through aggregating the data over an entire asparagus season, and the top plants can be cloned and placed in an asparagus breeding program. This would improve the yield of asparagus paddocks, and could lead to disease resistant asparagus plants.

8.2. Implementation Plan

The guiding document prepared earlier in the project has a complete list of recommendations for the commercial development of an automated asparagus harvester, see appendix D. The main recommendations are mentioned below.

The largest financial return would be achieved through the directors of TTC creating a new business which harvests asparagus for TTC and other asparagus growers using the automated harvesters. This harvesting is likely to be on contract to asparagus growers at a fixed rate per kilogram of asparagus while ensuring that all of the designated asparagus will be harvested for the defined duration. This method also reduces the liability of TTC if things do not go as planned.

TTC should obtain one other investor to assist in the development and utilisation of automated asparagus harvesters. This reduces the required investment from TTC, but also reduces the return that TTC will receive. Obtaining another investor is important because TTC is not likely to have enough money to develop an automated asparagus harvester by themselves. With the development of an automated asparagus harvester having an inherent risk, this method reduces the amount of money that TTC will lose if the development is not successful.

Once another investor has been obtained the company to develop the automated asparagus harvesters will need to be chosen. Industrial Research Limited (IRL) is a Crown Research Institute who has expressed interest in developing automated asparagus harvesters. IRL has a large amount of experience related to automation with industrial applications. The probability of IRL succeeding in developing an automated harvester that performs well in asparagus fields is high compared to Universities which are better suited for developing technology for laboratory conditions. Once the TTC directors have created a new business and obtained another investor, other companies capable of developing a viable automated harvester may have been made aware of. All viable companies will need to be assessed and compared in order to determine the most suitable developer.

After the automated harvesters have been developed the best return will be obtained through harvesting asparagus in New Zealand and in California. This is because the asparagus seasons do not overlap, and the growing conditions are very similar. The Californian asparagus season is longer than the New Zealand asparagus season which is predicted to return a larger profit than the New Zealand asparagus harvesting period of the year. The wage rate in California is similar to that in New Zealand, opposed to other major asparagus growing countries. There is a large amount of green asparagus grown in California therefore the chance of finding asparagus growers to harvest for is high.

Through following the above steps favourable financial figures are expected, see table 8.

Financial Summary ($000)										
Year	1	2	3	4	5	6	7	8	9	10
Accumulated Investment	$265	$546	$844	$896	$798	$379	$ -	$ -	$ -	$ -
Cash Flow	-$250	-$250	-$250	-$2	$144	$440	$736	$1,032	$1,328	$1,624
Accumulated Profit	$ -	$ -	$ -	$ -	$ -	$ -	$357	$1,388	$2,716	$4,340
Net Present Value	-$241	-$473	-$697	-$733	-$671	-$435	-$58	$424	$987	$1,613
Internal Rate of Return	0%	0%	0%	0%	0%	0%	8%	20%	28%	33%

Table 8) The financial figures for the business that should be created to develop and utilize automated asparagus harvesters

8.3. Media Attention

This project has received positive and negative attention. Some people are interested in the technological aspects, while others focus on an idea that this will be taking jobs away from people. The triple bottom line (TBL) is a tool for measuring organisational success that can also be used to combat negative attention. The three bottom lines in this tool are people, planet, and profit. Keeping these points in mind and conveying them to disapproving parties may change their opinions.

People

TTC must continue to use fair practices regarding labour, the community, and their region. None of these areas should be compromised, and none of them need to be with automated harvesting. Automated harvesting will employ more locals in the asparagus pack house where they are willing to work. The increase in workers receiving an income and the increased turnover from TTC will result in more money being spent within the community and the region, rather than the current pickers from Samoa taking money out of the country. Automated harvesting would take money away from the Samoan workers, however if asparagus keeps being harvested by hand then it may become uneconomical for asparagus to be grown by TTC, resulting in a larger number of jobs lost.

Planet

TTC must continue to adopt sustainable environmental practices. If the size of asparagus spears could be calculated accurately and the RTK-GPS system was integrated into the harvester the asparagus growth could be closely monitored. The use of fertiliser, herbicides, and fungicides could all be observed to determine the smallest possible application that is required. This will prevent unnecessary chemicals and fertilisers from leeching into the soil rather than being absorbed by the plants. Best growing practices could also be developed since there would be a new and accurate method to measure asparagus growth throughout the asparagus season.

Profit

TTC would be making a larger profit from the development of automated asparagus harvesters, and a large portion of this would be spent in the New Zealand economy. During the New Zealand asparagus off-season the automated harvester should be used in California which would result in money from overseas being brought into New Zealand. This would benefit society as a whole.

9. Close

This project has been a major learning curve for the student. The project spanned a long period of time and required work to be completed alongside other commitments. This required thorough project planning and project management. Some of the skills required for planning and managing the project were directly related to the Master of Engineering Management (MEM) coursework, however every project is different so a large portion of the skills were learnt while completing the project. The skills developed will be priceless for the student in his first full-time job as a project engineer/project manager for one of New Zealand's leading companies.

The student learned what methods and subsystems work and what systems do not work well when taking a system developed in a workshop into asparagus paddocks. It is the first time a system designed by the student has been tested in the required environment, which proved to be very different to the familiar laboratory conditions. This knowledge will also be helpful in industry.

Alongside the student gaining invaluable project management experience TTC received important information from a low-cost project. Technical suggestions and financial projections will now be able to assist TTC when deciding whether to invest a large amount of money into developing an automated asparagus harvester.

10. References

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8. Irie, N., et al., *Development of Asparagus Harvester Coordinated with 3-D Vision Sensor*, 2009.

A. Appendix 1

What is your full name?	What is the name of your asparagus growing business?	In terms of functionality, how important is it that an automated asparagus harvested is autonomous? (Does not require a driver/operator) (Keep in mind extra functionality incurs extra design and manufacturing costs)		How important is it that an automated asparagus harvester stores and recalls data about the size of asparagus spears throughout paddocks to show high and low producing areas?		How important is it that an automated asparagus harvester identifies the quality of asparagus spears (eg. domestic/export) before sorting them into appropriate storage crates?		How important is it that an automated asparagus harvester can sort spears into crates according to the size (Small/Medium/Long and/or Short/Medium/Long)?		How important is the tradeoff between speed and accuracy in an automated asparagus harvester?	
		Qualitative	Quantitative	Qualitative	Quantitative	Qualitative	Quantitative	Qualitative	Quantitative	Qualitative (accuracy)	Quantitative
Colin Petterson	CN & JJ Petterson	Unimportant	2	Important	4	Very Important	5	Very Important	5	95%+	4
Simon Turney	Mangaweka Asparagus	Important	4	Important	4	Unimportant	2	Unimportant	2	80%+	3
Lloyd Manville	The Manville Family Trust	Neither Unimportant or Important	3	Important	4	Unimportant	2	Unimportant	2	95%+	4
Peter George Falloon	Lakelands Asparagus Ltd	Neither Unimportant or Important	3	Important	4	Important	4	Very Important	5	95%+	4
Mark Hyslop	*Hyslop Partnership*	*Unimportant*	*2*	*Very Unimportant*	*1*	*Very Unimportant*	*1*	*Very Unimportant*	*1*	*95%+*	*4*
Geoff Lewis	Lewis Farms	Unimportant	2	Important	4	Important	4	Important	4	95%+	4
Average			2.8		4		3.4		3.6		3.8
Standard Deviation			0.836660027		0		1.341640786		1.516575089		0.447213595

Table A.1) Raw survey results from six different NZ asparagus growers

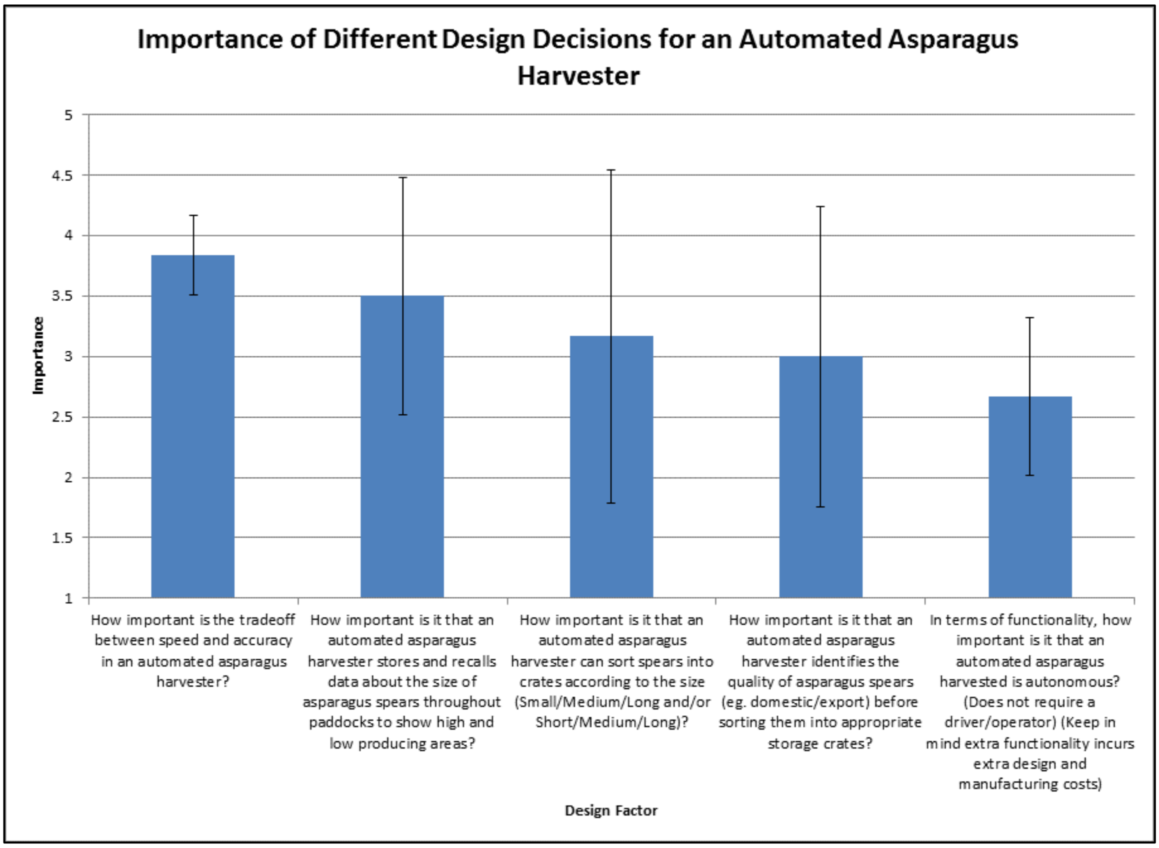

Figure A.2) Survey results including the outlier

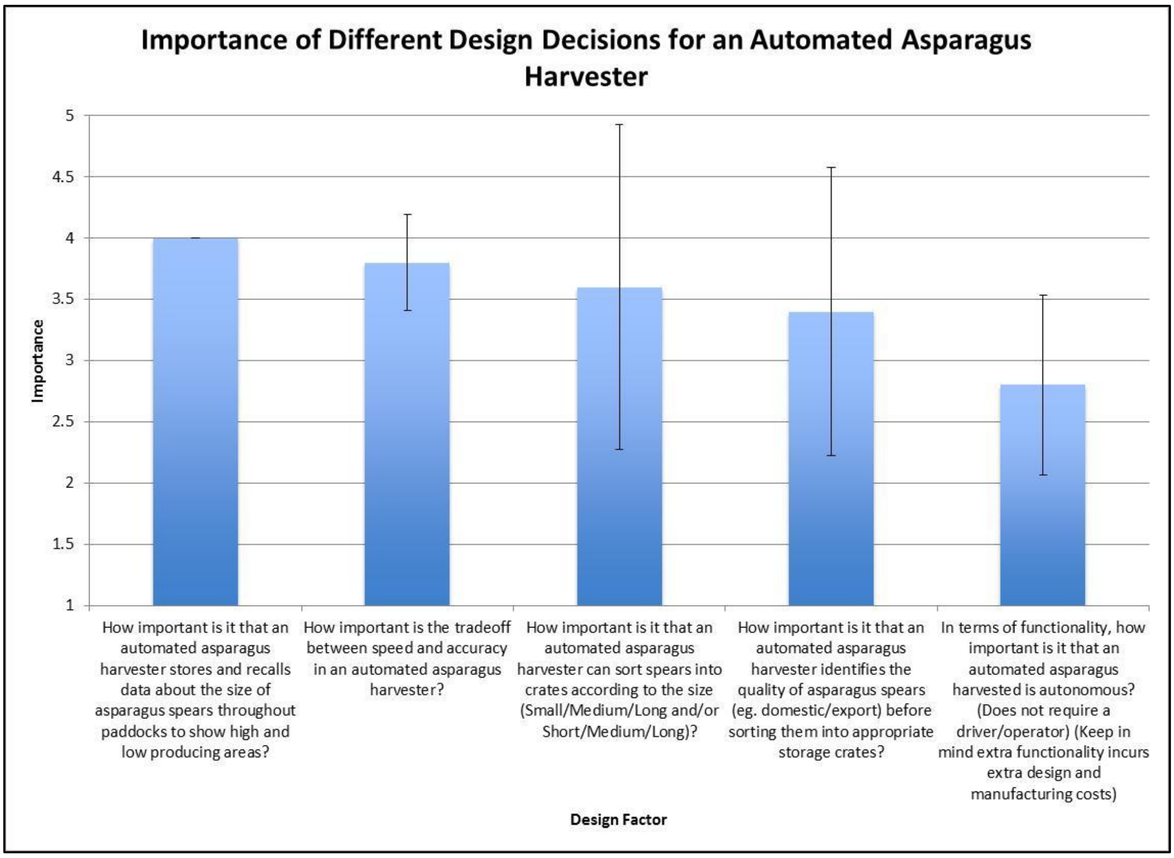

Figure A.3) Survey results excluding the outlier

Work Breakdown Structure (WBS)		Description
Task	Milestone	
1		**MEM project**
1.1		**Technical tasks**
1.1.1		Confirmation of design decisions
	1.1.2	Design decisions confirmed
1.1.3		Background research
	1.1.4	Background research completed
1.1.5		Develop camera calibration software
	1.1.6	Camera calibration software completed
1.1.7.1		Develop asparagus detection software (part 1)
1.1.7.2		Develop asparagus detection software (part 2)
	1.1.8	Asparagus detection software completed
1.1.9		Develop asparagus location logging
	1.1.10	Asparagus location logging completed
1.1.11		Develop camera mounting system
	1.1.12	Camera mounting system completed
1.1.13		Develop a mobile test rig
	1.1.14	Mobile test rig completed
1.1.15		System testing & improvements
	1.1.16	Obtain approval of performance
1.1.17		Asparagus cutting angle of approach software
	1.1.18	Asparagus cutting angle of approach software completed
1.2		**Financial analysis**
1.2.1		Cost saving analysis
1.2.2		Alternate revenue streams analysis
1.2.3		Business Plan Development
	1.2.4	Obtain approval of assumptions and analysis
1.3		**MEM requirements**
	1.3.1	Video presentation submitted
	1.3.2	Draft project report submitted
	1.3.3	Final project report version 1 submitted
	1.3.4	Updated final project report submitted

Table A.4) The tasks and milestones for the project

First Day of Week	Week Number	Week by Week Hours		Accumulated Hours		Schedule Status	Notes
		Budgeted Hours	Actual Hours	Budgeted Hours	Actual Hours		
Start	0	0	0	0	0	Start	Start
2/7/2012	1	15.5	1	15.5	1	Behind 14.5	Full-Time MEM
9/7/2012	2	15.5	1	31	2	Behind 29	Full-Time MEM
16/7/2012	3	15.5	1.5	46.5	3.5	Behind 43	Full-Time MEM
23/7/2012	4	15.5	10.8	62	14.3	Behind 47.7	Full-Time MEM
30/7/2012	5	15.5	9.8	77.5	24.1	Behind 53.4	Full-Time MEM
6/8/2012	6	15.5	35.1	93	59.2	Behind 33.8	Full-Time MEM
13/8/2012	7	15.5	23.7	108.5	82.9	Behind 25.6	Full-Time MEM
20/8/2012	8	15.5	20.4	124	103.3	Behind 20.7	Full-Time MEM
27/8/2012	9	15.5	36.2	139.5	139.5	Ahead 0	Full-Time MEM
3/9/2012	10	15.5	21.3	155	160.8	Ahead 5.8	Full-Time MEM
10/9/2012	11	15.5	13.4	170.5	174.2	Ahead 3.7	Full-Time MEM
17/9/2012	12	15.5	17.8	186	192	Ahead 6	Full-Time MEM
24/9/2012	13	15.5	5.8	201.5	197.8	Behind 3.6	Full-Time MEM
1/10/2012	14	47	33.2	248.5	231	Behind 17.5	Full-Time Project
8/10/2012	15	47	53.4	295.5	284.4	Behind 11.1	Full-Time Project
15/10/2012	16	47	57.4	342.5	341.8	Behind 0.6	Full-Time Project
22/10/2012	17	47	48	389.5	389.8	Ahead 0.3	Full-Time Project
29/10/2012	18	47	48.6	436.5	438.4	Ahead 1.9	Full-Time Project
5/11/2012	19	47	46.2	483.5	484.6	Ahead 1.1	Full-Time Project
12/11/2012	20	47	46.7	530.5	531.3	Ahead 0.8	Full-Time Project
19/11/2012	21	47	49.7	577.5	581	Ahead 3.5	Full-Time Project
26/11/2012	22	6.5	1.5	584	582.5	Behind 1.4	Full-Time Job
3/12/2012	23	6.5	9.2	590.5	591.7	Ahead 1.2	Full-Time Job
10/12/2012	24	6.5	12.5	597	604.2	Ahead 7.2	Full-Time Job
17/12/2012	25	47	47	644	651.2	Ahead 7.2	Full-Time Project
24/12/2012	26	47	46.3	691	697.5	Ahead 6.5	Full-Time Project
31/12/2012	27	24	37.2	715	734.7	Ahead 19.7	Full-Time Project

Table A.5) The project planning and tracking with regards to time

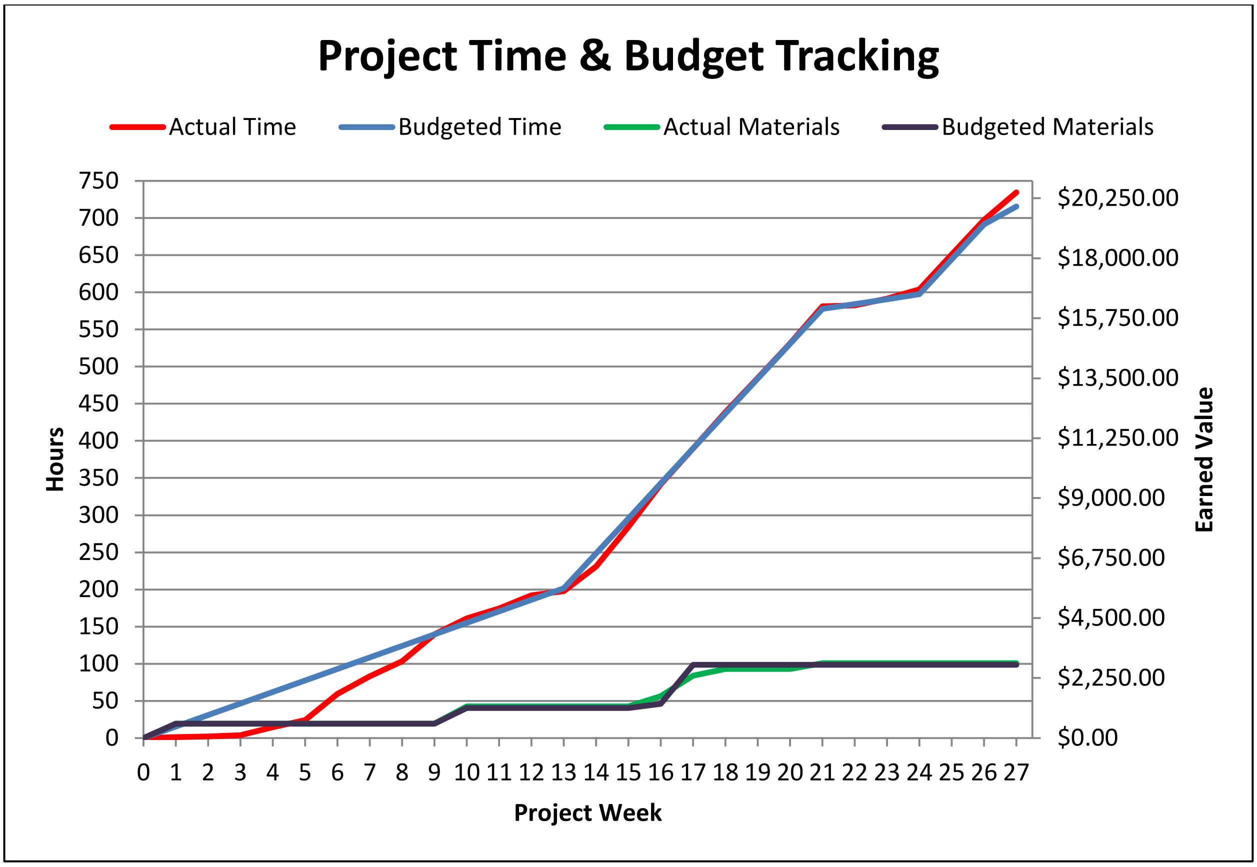

Figure A.6) The budgeted and actual project hours tracking for the project

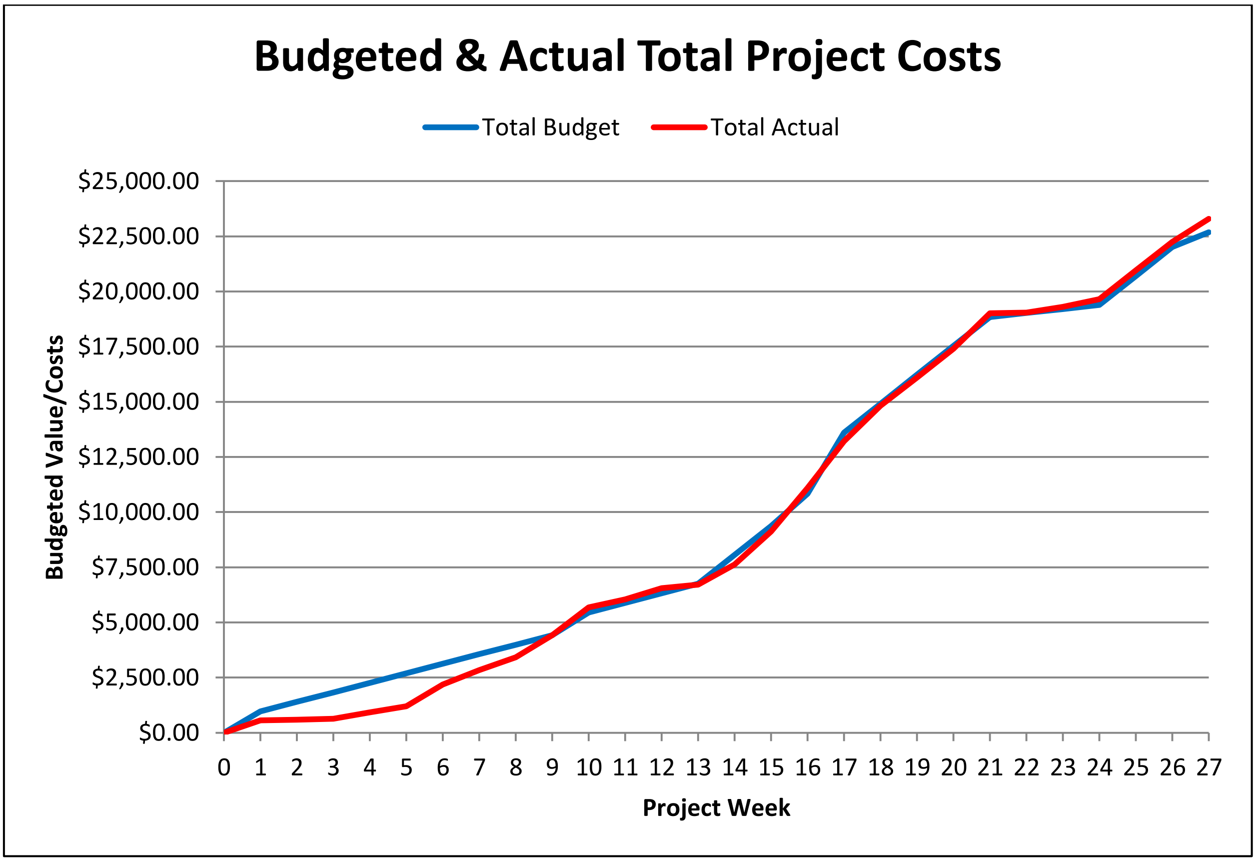

Figure A.7) The total project costs tracking

Day	June		July		August		September		October		November		December		January	
	Hours	Description	Hours	Description	Hours	Description	Hours	Description	Hours	Description	Hours	Description	Hours	Description	Hours	Description
1					1.6	Software language resear	9.3	Calibration code (Finding	5.6	Harvesting GUI	8.7	Getting & moving equipn			12.6	Asparagus detections tes
2					4.1	Setting up project softwa	6.7	GUI Design	3.9	Milestone Reports (1-3)	7.5	Fixing calibration, testing	1.5	Collating Data	11.4	Asparagus detection testi
3					1.3	IP Strategy	3.5	Qt Study & GUI functiona			7.1	Ellipse calculations, spea				
4			1	Creating Survey			1.2	3D Mathematics	3.1	Harvesting GUI						
5							5.8	GUI Functionality	4.8	Harvesting GUI			2.6	Formatting Data		
6					7.2	Setting up project softwa	6.2	GUI Functionality	6.2	Harvesting GUI	8.8	Automatic/Manual functi	2.9	Formatting Data		
7							2.8	Ordering Components	9.6	GPS Data Logging	9.5	InterfaceKit passing, 3d t				
8					4	C++ study	1.8	Connecting to Cameras	7	GPS Data Logging (1.9-Pro	8.9	Calibration and Recalibra				
9					5.6	C++ study			8.4	GPS Google Earth Output	8.6	Calibration and spear loc	3.7	Collating and Formatting		
10					5.3	Software structuring			8.6	GPS Software Integration	8.2	Camera mount fabricatio	2.3	Formatting Data		
11	4	Financial analysis(Bundli			8	Software structuring (4) &			8.4	Custom Data Retrieval	2.2	Updating budget, milestc	3.4	Formatting Data		
12					5	Creating Project Proposal			8.2	Code commenting & gen	8.5	Camera lighting fabricati				
13									6.6	General Code Functionali	12.2	Camera mount fabricatio				
14									6.2	General Code Functionali	8.3	Camera lighting fabricatio	3.8	Formatting Data		
15	1	MSI Meeting with Rob La	1	Formatting Survey Result	5.8	Calibration code	5.2	GUI Functionality	8.3	General Code Functionali	12	Camera lighting fabricatio				
16					6.8	Calibration code	8.2	GUI Functionality	8.2	Finishing GPS Milestone(	5.7	Milestone report (1.5), te	3	Different Finance Option		
17					3.7	Calibration code	2.5	Project Plan	8.1	LED controller & Progress			7.1	Revenue Generation Ana		
18							8.6	Project Charter	9.6	Buying test rig componen			8.2	Revenue Generation Ana		
19					6.1	Calibration code (cube ec	6.7	Project Charter	7.3	Interfacing IR Sensors, fir	8.4	Test rig fabriaction and co	2.5	International Harvesting		
20	4	MSI Application	1	Patent Researching	1.3	Calibration code (cube ec			8.4	Finding Qt Bug (5), Interfa	8.7	Test rig fabrication	7.9	Business Plan Developme		
21	4	MSI Application			4.1	Calibration code (cube ec			7.5	Setting up & capturing as	9.8	Test rig fabrication	8.3	Business Plan developme		
22			0.5	Updating Survey Results	1.9	Calibration code (cross-p			10.7	Setting up asparagus test	11	Presentation video recor	4.6	Business Plan Developme		
23			4.6	Patent Searches on Simil					8.1	Asparagus illumination m	6.8	Mileston Report, Progres	8.4	Test Rig Testing Preparat		
24			4.3	Patent Searches on Subsy	1	Calibration code	1.4	Progress Report	8.2	Post-Isolation software	5	Video recording and edit	6.8	Test Rig Testing Preparat		
25	2	MSI Application	1.9	Academic Research Pape	4.5	Calibration code			8.1	Post-Isolation software			0	*Milking the cows*		
26	4	MSI Application			7.6	Calibration code (matrix			9.1	Post-Isolation software			0	*Milking the cows*		
27	1.5	IRL Meeting with Patrick			8.6	Calibration code			3.8	Post-Isolation software			11.3	Finding the bug that prev		
28					6	Calibration code	4.4	Calibration debug file im					10.8	Rig preparation (3), busin		
29					3.8	Calibration code			8.2	3D maths software, Desig			9.2	Test Rig Testing and Mod		
30			2.8	IP Related Work	1.8	Calibration code (comple			6.9	3D maths software			8.2	Asparagus detection imp		
31									10.2	Progress Report (1.6), Ca			13.2	Asparagus detection imp		
Month TOTAL	20.5		17.1		105.1		74.3		217.3		165.9		129.7		24	
Cumulative TOTAL	20.5		37.6		142.7		217		434.3		600.2		729.9		753.9	

Table A.8) The hours logged each day throughout the project

Project Task	Hours		Materials		Budgeted Cost of Work	
	Budgeted	Actual	Budgeted	Actual	Scheduled (BCWS)	Performed (BCWP)
Confirmation of design decisions	34	4	$0.00	$0.00	$948.08	$111.54
Background research	48	21.6	$0.00	$0.00	$1,338.46	$602.31
Camera calibration software/system	135.5	149.5	$350.00	$330.44	$4,128.37	$4,499.19
Asparagus detection software/system	188	185.2	$1,453.04	$1,386.07	$6,695.35	$6,550.30
Asparagus location logging software/system	94	76.4	$100.00	$137.16	$2,721.15	$2,267.54
Camera mounting system	47	46.7	$150.00	$153.48	$1,460.58	$1,455.69
Mobile test rig	39.5	39.1	$689.11	$741.65	$1,790.55	$1,831.93
Testing + Improvements	78	78.1	$0.00	$0.00	$2,175.00	$2,177.79
Alternate revenue streams analysis	20	20.8	$0.00	$0.00	$557.69	$580.00
Cost saving analysis	36.5	19.5	$0.00	$0.00	$1,017.79	$543.75
Business Plan Development	20	27.9	$0.00	$0.00	$557.69	$777.98
Project Management Requirements	0	69.8	$0.00	$0.00	$0.00	$1,946.35
Other	39	24.5	$0.00	$0.00	$1,087.50	$683.17
TOTAL	**779.5**	**763.1**	**$2,742.15**	**$2,748.79**	**$24,478.21**	**$24,027.54**

Table A.9) The hours, materials and budgeted cost of work scheduled and performed for the project

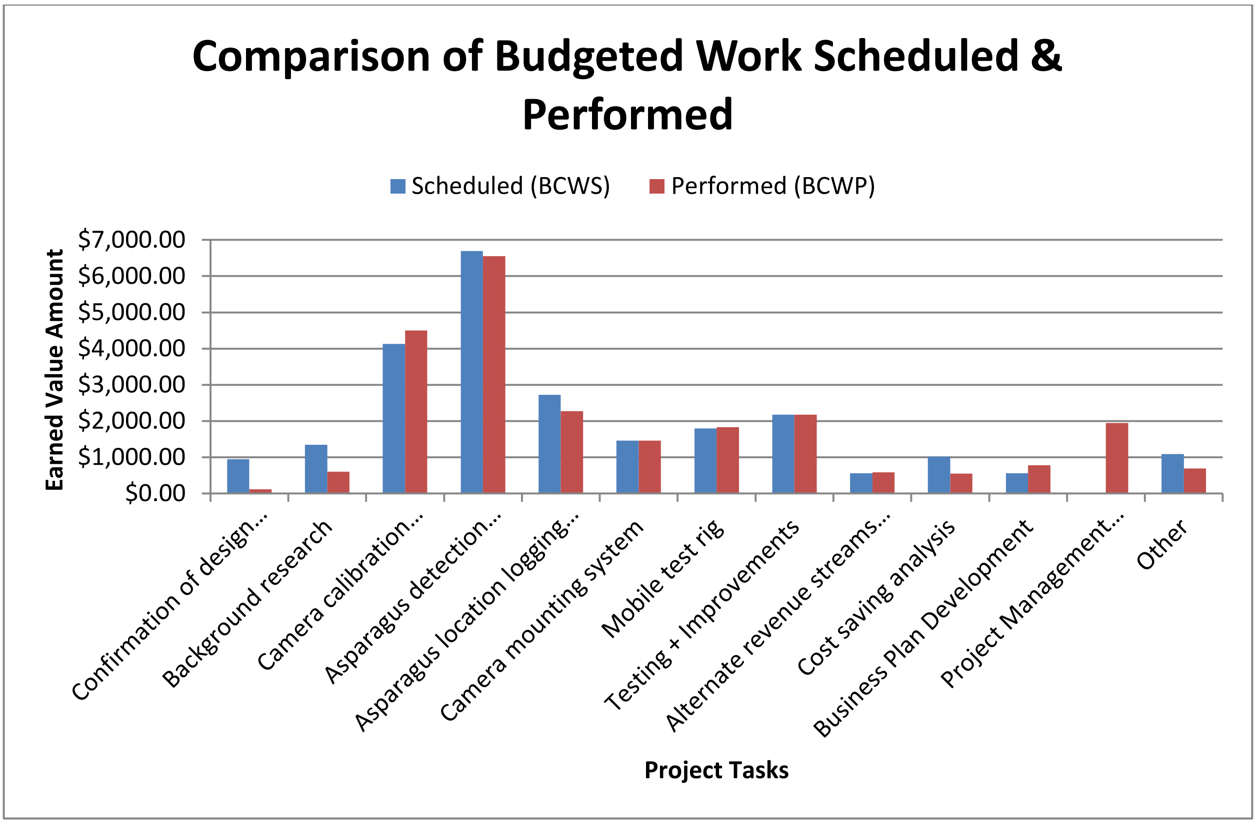

Figure A.10) The budgeted cost of work scheduled and performed for the project tasks

Date	Budget		Actual	
	Time	Accumulated Time	Time	Accumulated Time
	0	0	0	0
22/12/2012	7	7	0	0
23/12/2012	0	7	8.4	8.4
24/12/2012	8	15	6.8	15.2
25/12/2012	8	23	0	15.2
26/12/2012	8	31	0	15.2
27/12/2012	8	39	11.3	26.5
28/12/2012	8	47	3	29.5
29/12/2012	7	54	9.2	38.7
30/12/2012	0	54	8.2	46.9
31/12/2012	8	62	13.2	60.1
1/1/2013	8	70	12.6	72.7
2/1/2013	8	78	5.4	78.1
End	78		78.1	

Table A.11) The time tracking data for task 1.1.15 – system testing and improvements

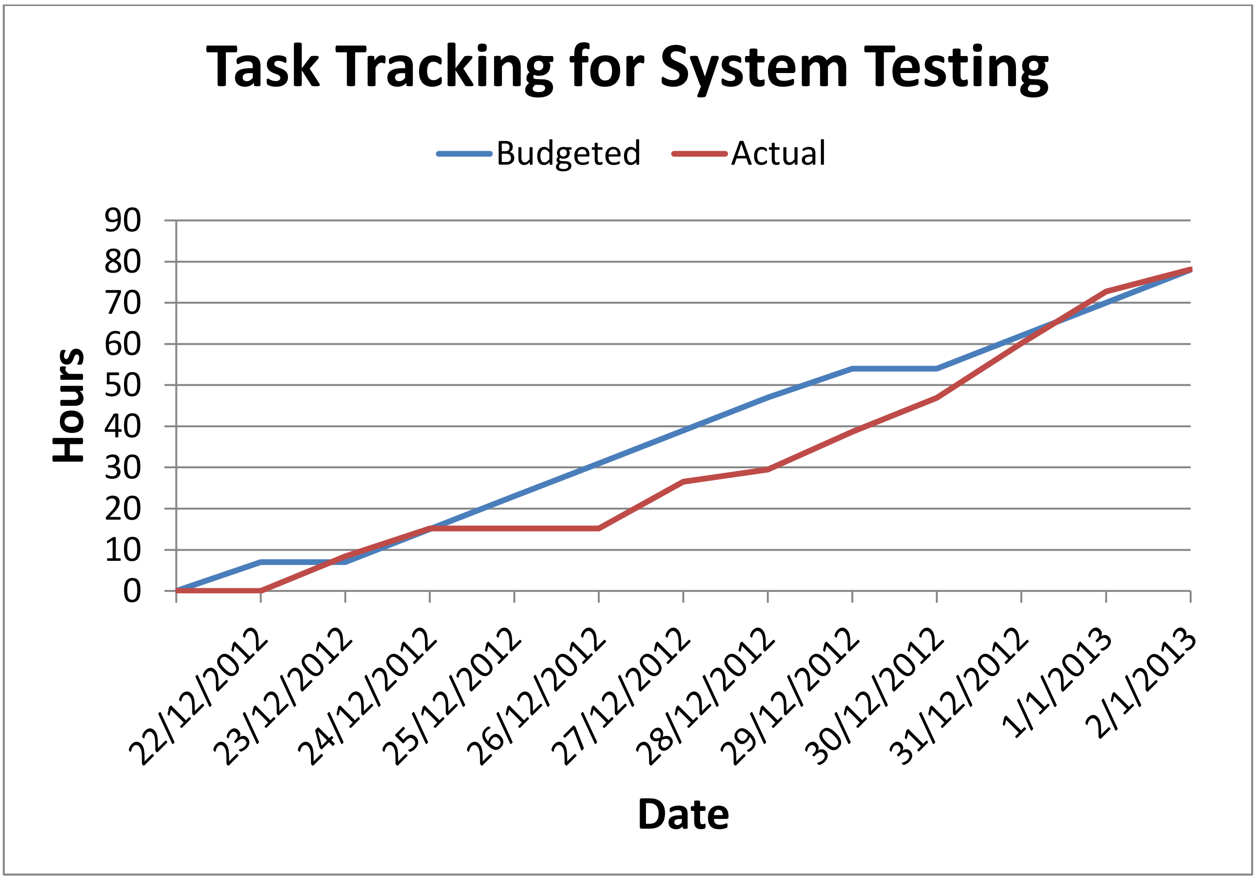

Figure A.12) The time tracking plot for task 1.1.15 – system testing and improvements

Budgeted Material Costs				
Quantity	Description	Cost		Planned Date of Purchase
		Excluding GST	Including GST	
1	Cameras	$180.00	$207.00	2/7/2012
1	Camera Calibration Equipment	$350.00	$402.50	2/7/2012
1	Asparagus Identification Components ex Basic Camera System	$500.00	$575.00	3/9/2012
1	Asparagus Location Logging Equipment	$100.00	$115.00	25/9/2012
1	Camera Mounting System Materials	$150.00	$172.50	15/10/2012
1	Test Rig Steel	$150.00	$172.50	22/10/2012
1	Test Rig 300W Pure Sine-Wave Inverter	$239.11	$269.00	22/10/2012
1	Test Rig Laptop	$773.04	$889.00	22/10/2012
1	Other Test Rig Materials	$300.00	$345.00	22/10/2012
TOTAL		$2,742.15	$3,147.50	

Table A.13) The budgeted project materials and planned purchase date

Actual Material Costs				
Quantity	Description	Cost		Date Purchased
		Excluding GST	Including GST	
2	Logitech C910 Web Cameras	$173.00	$198.95	24/1/2012
1	Custom Calibration Cube	$330.44	$380.01	26/10/2011
1	Garmin GPS 18 OEM	$77.59	$77.59	7/9/2012
1	Globalsat BU-353S4	$59.57	$59.57	7/9/2012
100	5mm LED Mixture Pack 1	$17.41	$17.41	7/9/2012
100	5mm LED Mixture Pack 2	$11.18	$11.18	7/9/2012
2	GP2Y0A02YK IR Sensor Kit	$84.48	$84.48	7/9/2012
1	Phidgets InterfaceKit 2/2/2	$82.02	$82.02	7/9/2012
1	Phidgets LED64 w/Power Supply	$199.72	$199.72	7/9/2012
2	Sharp IR Distance Sensor - GP2D12 Alternative	$42.49	$42.49	7/9/2012
1	Veroboard and Cutting Tool	$42.00	$48.30	9/9/2012
50	Extension Wires	$43.48	$50.00	9/9/2012
2	Black Curtains and Backing	$34.15	$39.36	18/10/2012
1	Projecta Pure Sine 12V 300W Inverter	$341.00	$392.15	19/10/2012
1	Test Rig Laptop (Estimated)	$750.00	$750.00	22/10/2012
160	Wide Angle LEDs	$25.78	$25.78	23/10/2012
1	Camera Mounting Steel	$68.00	$78.20	30/10/2012
1	Test Rig Steel	$182.00	$209.30	30/10/2012
2.5	Extra Black Curtains and Backing	$29.50	$33.92	19/11/2012
1	Test Rig Fasteners	$5.00	$5.75	19/11/2012
1	Test Rig Plywood	$150.00	$172.50	19/11/2012
1	Fabrication Miscellaneous Items (Welding etc)	$30.00	$34.50	19/11/2012
TOTAL		$2,778.79	$2,993.17	

Table A.14) The actual material costs and purchase dates, note some items were imported so did not incur GST

First Day of Week	Week Number	Week by Week Earned Time Value		Accumulated Earned Time Value		Week by Week Material Costs		Accumulated Material Costs	
		Budgeted Value	Actual Value	Budgeted Value	Actual Value	Budgeted Materials	Actual Materials	Budgeted Materials	Actual Materials
Start	0	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2/7/2012	1	$432.21	$27.88	$432.21	$27.88	$530.00	$503.44	$530.00	$530.00
9/7/2012	2	$432.21	$27.88	$864.42	$55.77	$0.00	$0.00	$530.00	$530.00
16/7/2012	3	$432.21	$41.83	$1,296.63	$97.60	$0.00	$0.00	$530.00	$530.00
23/7/2012	4	$432.21	$301.15	$1,728.85	$398.75	$0.00	$0.00	$530.00	$530.00
30/7/2012	5	$432.21	$273.27	$2,161.06	$672.02	$0.00	$0.00	$530.00	$530.00
6/8/2012	6	$432.21	$978.75	$2,593.27	$1,650.77	$0.00	$0.00	$530.00	$530.00
13/8/2012	7	$432.21	$660.87	$3,025.48	$2,311.63	$0.00	$0.00	$530.00	$530.00
20/8/2012	8	$432.21	$568.85	$3,457.69	$2,880.48	$0.00	$0.00	$530.00	$530.00
27/8/2012	9	$432.21	$1,009.42	$3,889.90	$3,889.90	$0.00	$0.00	$530.00	$530.00
3/9/2012	10	$432.21	$593.94	$4,322.12	$4,483.85	$600.00	$659.93	$1,130.00	$1,189.93
10/9/2012	11	$432.21	$373.65	$4,754.33	$4,857.50	$0.00	$0.00	$1,130.00	$1,189.93
17/9/2012	12	$432.21	$496.35	$5,186.54	$5,353.85	$0.00	$0.00	$1,130.00	$1,189.93
24/9/2012	13	$432.21	$161.73	$5,618.75	$5,515.58	$0.00	$0.00	$1,130.00	$1,189.93
1/10/2012	14	$1,310.58	$925.77	$6,929.33	$6,441.35	$0.00	$0.00	$1,130.00	$1,189.93
8/10/2012	15	$1,310.58	$1,489.04	$8,239.90	$7,930.38	$0.00	$0.00	$1,130.00	$1,189.93
15/10/2012	16	$1,310.58	$1,600.58	$9,550.48	$9,530.96	$150.00	$375.15	$1,280.00	$1,565.08
22/10/2012	17	$1,310.58	$1,338.46	$10,861.06	$10,869.42	$1,462.15	$775.78	$2,742.15	$2,340.86
29/10/2012	18	$1,310.58	$1,355.19	$12,171.63	$12,224.62	$0.00	$250.00	$2,742.15	$2,590.86
5/11/2012	19	$1,310.58	$1,288.27	$13,482.21	$13,512.88	$0.00	$0.00	$2,742.15	$2,590.86
12/11/2012	20	$1,310.58	$1,302.21	$14,792.79	$14,815.10	$0.00	$0.00	$2,742.15	$2,590.86
19/11/2012	21	$1,310.58	$1,385.87	$16,103.37	$16,200.96	$0.00	$214.50	$2,742.15	$2,805.35
26/11/2012	22	$181.25	$41.83	$16,284.62	$16,242.79	$0.00	$0.00	$2,742.15	$2,805.35
3/12/2012	23	$181.25	$256.54	$16,465.87	$16,499.33	$0.00	$0.00	$2,742.15	$2,805.35
10/12/2012	24	$181.25	$348.56	$16,647.12	$16,847.88	$0.00	$0.00	$2,742.15	$2,805.35
17/12/2012	25	$1,310.58	$1,310.58	$17,957.69	$18,158.46	$0.00	$0.00	$2,742.15	$2,805.35
24/12/2012	26	$1,310.58	$1,291.06	$19,268.27	$19,449.52	$0.00	$0.00	$2,742.15	$2,805.35
31/12/2012	27	$669.23	$1,037.31	$19,937.50	$20,486.83	$0.00	$0.00	$2,742.15	$2,805.35

Table A.15) The budgeted and actual project costs including earned time value and materials

First Day of Week	Week Number	Total Accumulated Costs		Budget Status
		Budgeted	Actual	
Start	0	$0.00	$0.00	Start
2/7/2012	1	$962.21	$557.88	Under $404.3
9/7/2012	2	$1,394.42	$585.77	Under $808.6
16/7/2012	3	$1,826.63	$627.60	Under $1199
23/7/2012	4	$2,258.85	$928.75	Under $1330
30/7/2012	5	$2,691.06	$1,202.02	Under $1489
6/8/2012	6	$3,123.27	$2,180.77	Under $942.5
13/8/2012	7	$3,555.48	$2,841.63	Under $713.8
20/8/2012	8	$3,987.69	$3,410.48	Under $577.2
27/8/2012	9	$4,419.90	$4,419.90	Under $0
3/9/2012	10	$5,452.12	$5,673.77	Over $221.6
10/9/2012	11	$5,884.33	$6,047.43	Over $163.1
17/9/2012	12	$6,316.54	$6,543.77	Over $227.2
24/9/2012	13	$6,748.75	$6,705.51	Under $43.2
1/10/2012	14	$8,059.33	$7,631.27	Under $428
8/10/2012	15	$9,369.90	$9,120.31	Under $249.5
15/10/2012	16	$10,830.48	$11,096.04	Over $265.5
22/10/2012	17	$13,603.21	$13,210.28	Under $392.9
29/10/2012	18	$14,913.79	$14,815.47	Under $98.3
5/11/2012	19	$16,224.37	$16,103.74	Under $120.6
12/11/2012	20	$17,534.94	$17,405.95	Under $128.9
19/11/2012	21	$18,845.52	$19,006.32	Over $160.7
26/11/2012	22	$19,026.77	$19,048.14	Over $21.3
3/12/2012	23	$19,208.02	$19,304.68	Over $96.6
10/12/2012	24	$19,389.27	$19,653.24	Over $263.9
17/12/2012	25	$20,699.85	$20,963.82	Over $263.9
24/12/2012	26	$22,010.42	$22,254.87	Over $244.4
31/12/2012	27	$22,679.65	$23,292.18	Over $612.5

Table A.16) The project budgeted and actual total costs

B. Progress Report

Project Status Report 9

<table>
<tr><td colspan="2">Project Title</td><td colspan="3">Automated Asparagus Harvester Feasibility Analysis</td></tr>
<tr><td colspan="2">Project Objectives</td><td colspan="3">This project will determine the feasibility and some market opportunities of designing and creating an automated asparagus harvester for The Tendertips Company. This will include:
• Financial justifications
• Market needs
• Technical requirements
• Design and construction of a asparagus identification and data-logging system
• Performance analysis of the designed system
• Possible revenue streams and predictions
• Future economic impacts</td></tr>
<tr><td colspan="2">Report Released By</td><td colspan="3">Andrew Lewis</td></tr>
<tr><td>Version</td><td>Author(s)</td><td>Date</td><td>Reporting Period</td><td>Distribution</td></tr>
<tr><td>1.0</td><td>Andrew Lewis</td><td>24-09-2012</td><td>2nd July 2012 – 24th September 2012</td><td>Geoff Lewis (Sponsor)
Piet Beukman (Supervisor)
Patrick Lim (Technical Supervisor)</td></tr>
<tr><td>2.0</td><td>Andrew Lewis</td><td>08-10-2012</td><td>24th September 2012 – 8th October 2012</td><td>Geoff Lewis (Sponsor)
Piet Beukman (Supervisor)
Patrick Lim (Technical Supervisor)</td></tr>
<tr><td>3.0</td><td>Andrew Lewis</td><td>17-10-2012</td><td>8th October 2012 - 17th October 2012</td><td>Geoff Lewis (Sponsor)
Piet Beukman (Supervisor)
Patrick Lim (Technical Supervisor)</td></tr>
<tr><td>4.0</td><td>Andrew Lewis</td><td>31-10-2012</td><td>17th October 2012 - 31st October 2012</td><td>Geoff Lewis (Sponsor)
Piet Beukman (Supervisor)
Patrick Lim (Technical Supervisor)</td></tr>
<tr><td>5.0</td><td>Andrew Lewis</td><td>14-11-2012</td><td>31st October 2012 – 14th November 2012</td><td>Geoff Lewis (Sponsor)
Piet Beukman (Supervisor)
Patrick Lim (Technical Supervisor)</td></tr>
</table>

6.0	Andrew Lewis	23-11-2012	14th November 2012 – 23rd November 2012	Geoff Lewis (Sponsor) Piet Beukman (Supervisor) Patrick Lim (Technical Supervisor)
7.0	Andrew Lewis	9-12-2012	24th November 2012 – 9th December 2012	Geoff Lewis (Sponsor) Piet Beukman (Supervisor) Patrick Lim (Technical Supervisor)
8.0	Andrew Lewis	20-12-2012	9th December 2012 – 20th December 2012	Geoff Lewis (Sponsor) Piet Beukman (Supervisor) Patrick Lim (Technical Supervisor)
9.0	Andrew Lewis	02-01-2013	21st December 2012 – 2nd January 2013	Geoff Lewis (Sponsor) Piet Beukman (Supervisor) Patrick Lim (Technical Supervisor)

1. Current Project Status

WBS	Task Name	Planned Start Date	Planned Finish Date	Planned Duration (hours)	Actual Start Date	Time Spent to Date	Current Forecast Completion Date	Actual Completion Date	Actual Time Taken to Complete (hours)
1	**MEM project**	**Mon 02/07/12**	**Sun 31/03/13**	**779.5**	**Mon 02/07/12**	**775.1**	**Sun 22/02/13**		**775.1**
1.1	**Technical tasks**	**Mon 02/07/12**	**Fri 01/02/13**	**664**	**Mon 02/07/12**	**600.6**		**Fri 02/01/13**	**600.6**
1.1.1	Confirmation of design decisions	Mon 02/07/12	Tue 17/07/12	34	Mon 02/07/12			Sun 15/07/12	4
1.1.2	Design decisions confirmed	Milestone	Tue 17/07/12					Sun 15/07/12	
1.1.3	Background research	Wed 18/07/12	Wed 08/08/12	48	Wed 18/07/12			Fri 03/08/12	21.6
1.1.4	Background research completed	Milestone	Wed 08/08/12					Fri 03/08/12	
1.1.5	Develop camera calibration software	Thu 09/08/12	Mon 01/10/12	135.5	Thu 09/08/12			Sat 29/09/12	149.5
1.1.6	Camera calibration software completed	Milestone	Mon 01/10/12					Sat 29/09/12	
1.1.9	Develop asparagus location logging	Tue 30/10/12	Mon 12/11/12	94	Sun 7/10/2012			Tue 16/10/12	76.4
1.1.10	Asparagus location logging completed	Milestone	Mon 12/11/12					Tue 16/09/12	

1.1.7.1	Develop asparagus detection software (part 1)	Tue 02/10/12	Mon 29/10/12	188	Tue 02/10/12			Sat 06/10/12	23.6
1.1.7.2	Develop asparagus detection software (part 2)	Sun 21/10/12	Mon 12/11/12		Wed 17/10/12			Fri 9/11/12	161.6
1.1.8	Asparagus detection software completed	Milestone	Mon 08/11/12					Fri 09/11/12	
1.1.11	Develop camera mounting system	Sat 9/11/12	Thu 15/11/12	47	Sun 10/11/12			Thu 15/11/12	46.7
1.1.12	Camera mounting system completed	Milestone	Thu 15/11/12					Thu 15/11/12	
1.1.13	Develop a mobile test rig	Fri 16/11/12	Thu 22/11/12	39.5	Fri 16/11/12			Thu 22/11/12	39.1
1.1.14	Mobile test rig completed	Milestone	Thu 22/11/12					Thu 22/11/12	
1.1.15	System testing & improvements	Sat 22/12/12	Wed 02/01/12	78	Sun 23/12/12			Wed 02/01/12	78.1
1.1.16	Obtain approval of performance	Milestone	Wed 02/01/12					Wed 02/01/12	
1.1.17	Asparagus cutting angle of approach software				INTEGRATED INTO TASK 1.1.15 and MILESTONE 1.1.16				
1.1.18	Asparagus cutting angle of approach software	Milestone							

	completed								
1.2	**Financial analysis**	**Sat 23/11/12**	**Fri 21/12/12**	**76.5**	**Sun 02/12/12**	**68.2**		**Fri 28/12/12**	**68.2**
1.2.1	Cost saving analysis	Fri 23/11/12	Sun 16/12/12	36.5	2/12/2012			Fri 14/12/12	19.5
1.2.2	Alternate revenue streams analysis	Mon 17/12/12	Wed 19/12/12	20	Sun 16/12/12			Wed 19/12/12	20.8
1.2.3	Business Plan Development	Wed 19/12/12	Fri 21/12/12	20	Thurs 20/12/12			Fri 28/12/12	27.9
1.2.4	Obtain approval of assumptions and analysis	Milestone	Fri 21/12/12					Fri 28/12/12	
1.3	**MEM requirements**	**Mon 26/11/12**	**Sun 31/03/13**	0		**81.8**	**Fri 22/02/13**		**81.8**
1.3.1	Video presentation submitted	Milestone	Mon 26/11/12					Sun 25/11/12	12
1.3.2	Draft project report submitted	Milestone	Fri 25/01/13				Fri 25/01/13		
1.3.3	Final project report submitted	Milestone	Fri 01/02/13				Fri 01/02/13		
1.3.4	Updated final project report submitted	Milestone	Fri 22/02/13				Fri 22/02/13		
1.3.5	Other (Ongoing reports etc.)	Mon 2/7/2012	Sun 22/2/2013				Fri 22/02/2013		69.8
1.4	**Other**	**Mon 02/07/2012**	**Sun 22/02/2013**	**39**		**24.5**	**Sun 22/02/2013**		**24.5**

Table 1.1) The project tasks and milestones

1.1. Progress

Since the last progress report tasks 1.2.3 and 1.1.16 have been completed. See section 2, project progress for more information.

1.2. Tracking

Currently the project is tracking on schedule. More details can be found in section 3, project tracking.

1.3. Risk

Risk Level	Risk Value
Low	1 => 5
Moderate	6 => 10
High	11 => 15
Extreme	16 => 30

Table 1.3.1) The project risk categories

Previous risk: 8.875
Current risk: 4.75

Risk Summary	Conclusion
Currently risks are manageable and project is expected to be complete to the original time and quality requirements.	Proceeding according to plan
	Manageable issues exist
	Serious issues

Table 1.3.2) The current project risk level

The technical and financial components of the project have been completed, therefore only the final report remains and the risk has decreased. More details can be found in the section 4, project risks.

1.4. Upcoming work

Before the next progress report is due:

- The final project report should be underway, and at least half completed.

More information can be found in section 5, upcoming work.

2. Project Progress

2.1. Technical Tasks

Task	Deliverable
1.1.1 Confirmation of design decisions	• Completed ahead of the deadline. The design decisions were confirmed from a range of New Zealand asparagus growers.
1.1.3 Background research	• Completed ahead of the deadline. Existing systems, associated patents, and academic papers were identified and researched.
1.1.5 Develop camera calibration software	• Completed ahead of the deadline. The software was developed using four test images, and this was been incorporated into a Graphical User Interface (GUI). The GUI includes debugging tools to assist task 1.1.15 once that commences.
1.1.7 Develop asparagus detection software	• Completed. The aims of the milestone were not met, however after task 1.1.15 they may be completed. All details regarding the GPS position, LED controller state, infrared sensor states are constantly updated in the GUI. The GUI also displays information regarding size and location for the most recent spear and all spears harvested on a particular day and farm. The images showing the results from software algorithms are also displayed for the most recent asparagus detection attempt.
1.1.9 Develop asparagus location logging	• Completed. The system is able to save the approximate GPS location and the size of asparagus spears in both a ".aspharv" file that can later be loaded into the harvesting software, as well as a ".kml" map file. The user is also able to save only asparagus spears that are of a range of sizes or within a certain percentile to a map file if desired. The colour of the markers for each asparagus spear range from green to red which is directly proportional to the size of asparagus spears. The analysis of these map files is possible in the free version of Google Earth.
1.1.11 Develop camera mounting system	• Completed. The camera mounting system allows a camera to be securely fastened, while the vertical location and the angle at which the camera faces the ground can easily be adjusted for testing purposes. The lighting system was also assembled and a similar constructed that allows for identical adjustments to be made with minimal interference with the cameras and their mounts.
1.1.13 Develop a mobile test rig	• Completed. A mobile test rig has been constructed that can be pushed along asparagus paddocks. The camera and lighting mounts are able to be attached and easily modified if required. The system has a power supply so the equipment can operate for long durations.
1.1.15 System testing and improvements	• Completed. Asparagus was not able to be tested as it grows in the rows however this was mimicked alongside the rows. The test rig performed well and the software detected the asparagus locations accurately. The asparagus spear lengths were and sizes were not very accurate. The GPS saved the location of each spear automatically and this could later be retrieved. The asparagus cutting angle of approach is also able to be easily calculated within the software.
1.1.17 Develop asparagus cutting angle of approach software	• INTEGRATED INTO TASK 1.1.15

Table 2.1.1) The status of the technical project tasks

Note: Project tasks have been designed to run sequentially rather than in parallel.

2.2. Financial Analysis Tasks

Task	Deliverable
1.2.1 Cost saving analysis	• Completed. Cost savings are expected to be made through automated asparagus harvesting with the expected automated harvesting cost equalling 29% of the 2011 manual harvesting cost.
1.2.2 Alternate revenue streams analysis	• Completed. Selling asparagus harvesters is possible however there are more suitable methods of generating revenue. It is not worthwhile to lease intellectual property to other automated solutions. Harvesting asparagus in California is one way that revenue can be generated, and it would not affect the performance of harvesting asparagus in New Zealand.
1.2.3 Business Plan Development	• Completed. The generated document was designed as a guiding document for the client containing information a business plan would have and other helpful information. This will give the client more guidance with what finances are expected, and how to proceed after the completion of this project.

Table 2.2.1) The status of the financial analysis project tasks

Note: Project tasks have been designed to run sequentially rather than in parallel.

2.3. MEM Requirements

Milestone	Deliverable
1.3.1 Video presentation	• Completed slightly ahead of schedule, 25/11/12.
1.3.2 Draft project report submitted	• Not yet started. Due on 25/01/2013.
1.3.3 Final project report version 1 submitted	• Not yet started. Due on 02/02/2013.
1.3.4 Updated final project report submitted	• Not yet started. Due on 22/02/2013.

Table 2.3.1) The status of the MEM project requirements

Note: Project tasks have been designed to run sequentially rather than in parallel. Due to the current progress of the project, there is no need to modify deadlines.

2.4. Current Task Progress Details

No tasks are currently underway.

3. Project Tracking

3.1. Overall Project Budget

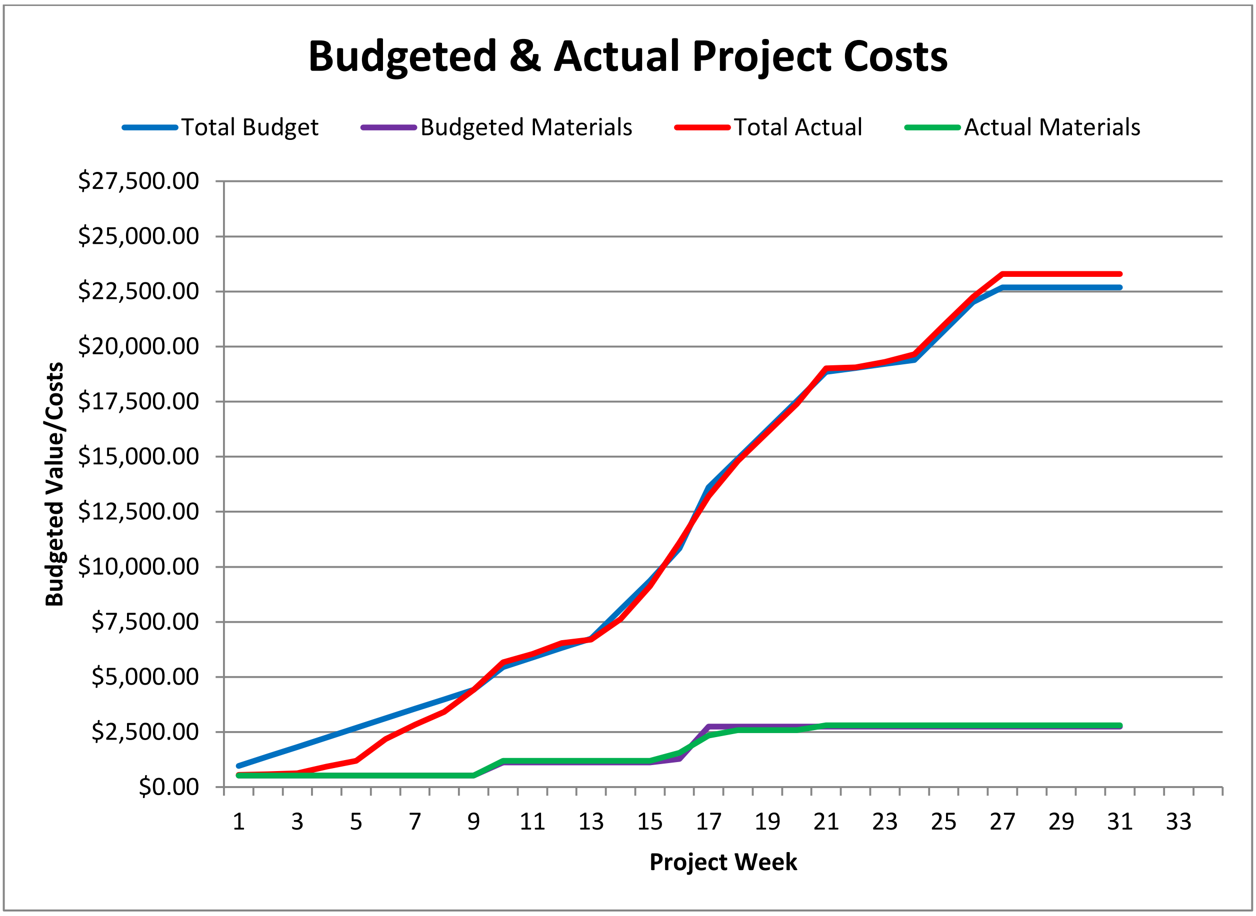

Figure 3.1.1) The current tracking of the project in terms of overall budget and material costs

The project finished slightly over budget.

- Budgeted project cost as at 02/01/2013 $22,679.65
- Actual project cost as at 02/01/2013 $23,292.18

All materials have been purchased and used.

- The budgeted material costs were $2,742.15
- The actual materials purchased to date is $2,805.35

No more materials are required.

NB. Budgeted and actual costs are taken from the completion of the previous week.

3.2. Project Hours Breakdown

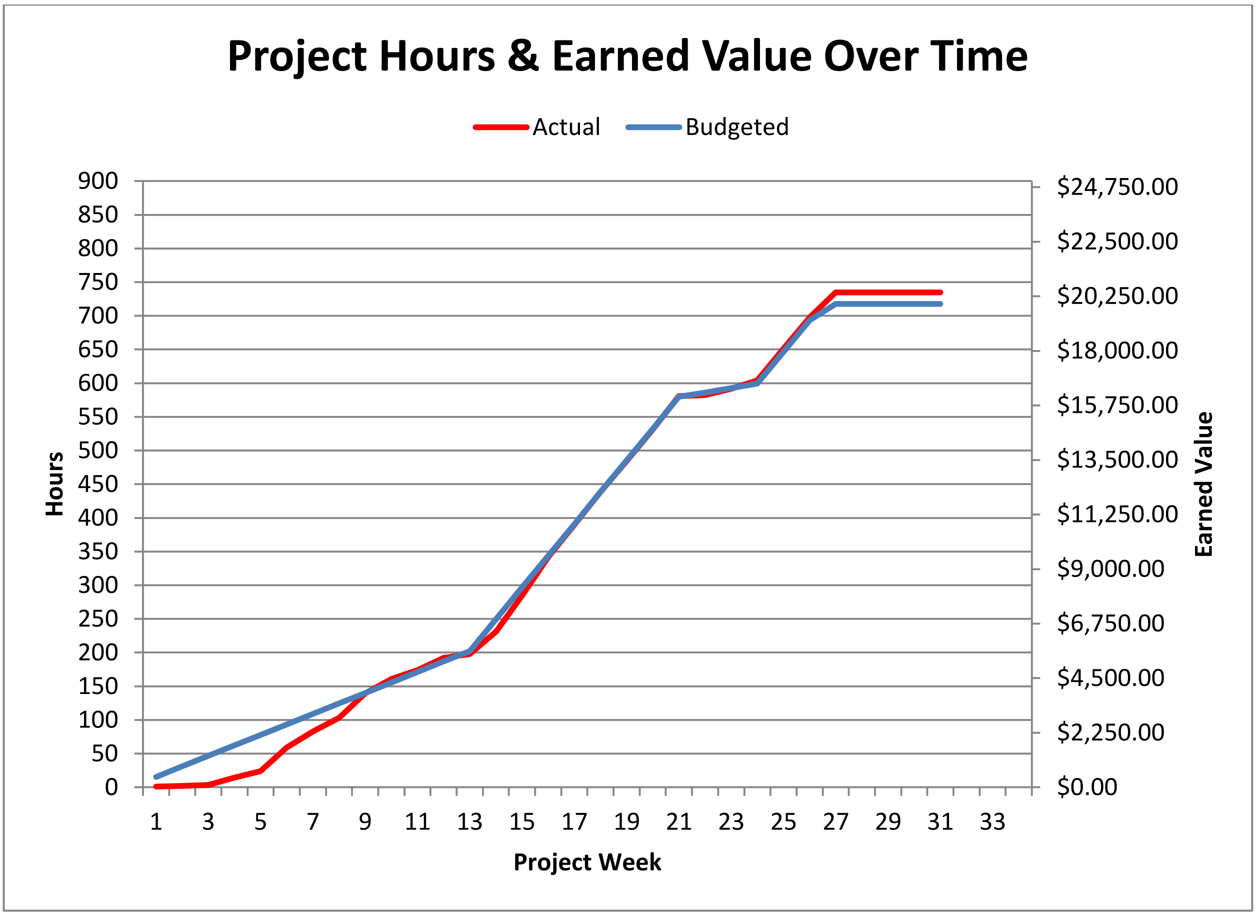

Figure 3.2.1) The current tracking of the project in terms of the earned value over time

The earned value due to hours spent on the project finished slightly over budget

- Budgeted project hours as at 02/01/2013 715
- Actual project hours as at 02/01/2013 734.7

NB. Budgeted and actual hours are taken from the completion of the previous week.

NB. Actual project hours do not include the 20.5 hours spent obtaining MSI funding.

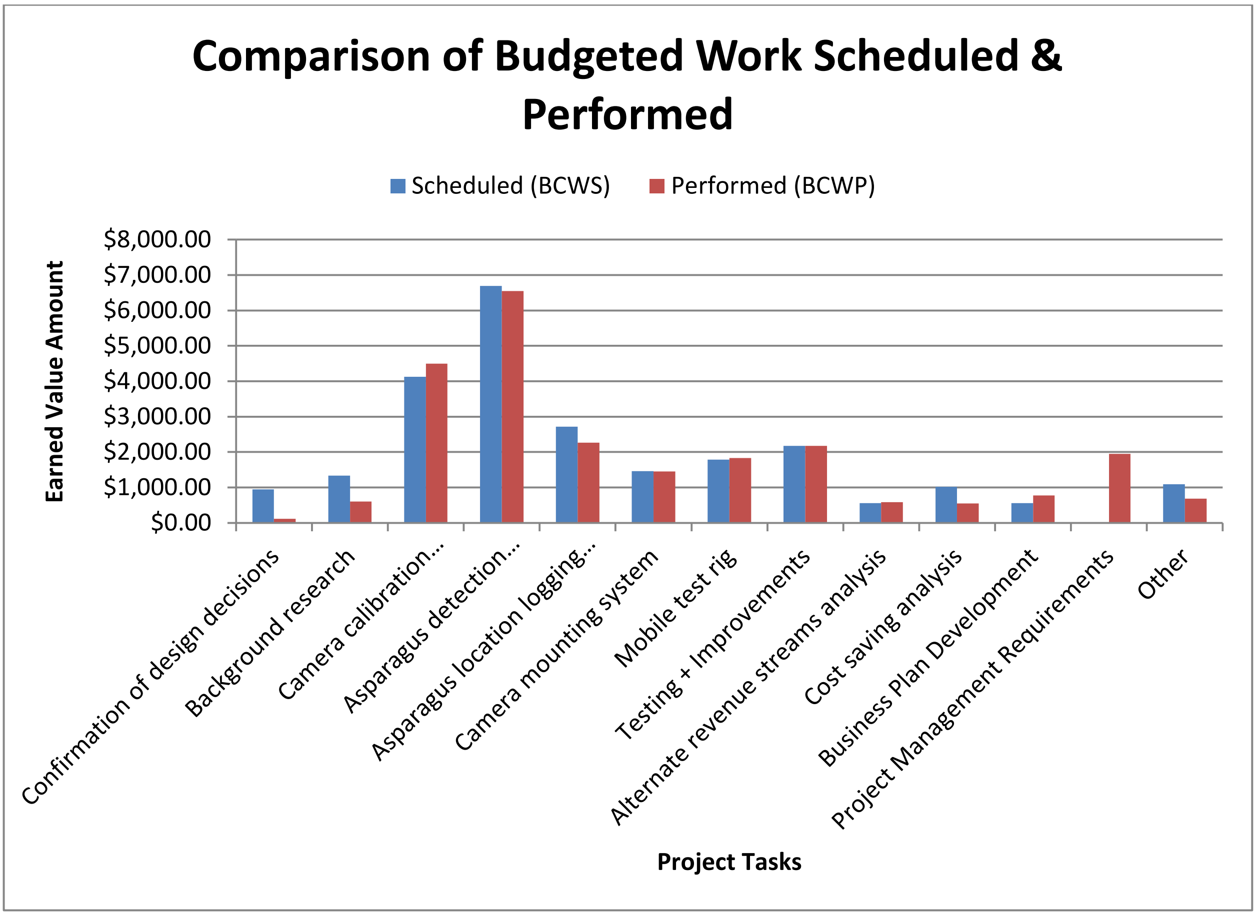

Figure 3.2.2) The current BCWS and BCWP for each project task

Care must be taken for no current or future tasks to go over budget, because no task time has been allowed for the ongoing project management requirements (reports etc.). The time spent on project management requirements (reports etc.) is however included in the overall project tracking, figure 3.2.1.

3.3. Project Quality

The technical and financial tasks were completed with no quality issues.

3.4. Project Programme

There have been no changes to the project programme, see figure 3.4.1.

ID	WBS	Task Name	Start	Finish
1	**1**	**MEM project**	**Mon 2/7/12**	**Fri 22/2/13**
2	**1.1**	**Technical tasks**	**Mon 2/7/12**	**Wed 2/1/13**
3	1.1.1	Confirmation of design decisions	Mon 2/7/12	Tue 17/7/12
4	1.1.2	Design decisions confirmed	Tue 17/7/12	Tue 17/7/12
5	1.1.3	Background research	Wed 18/7/12	Wed 8/8/12
6	1.1.4	Background research completed	Wed 8/8/12	Wed 8/8/12
7	1.1.5	Develop camera calibration software	Thu 9/8/12	Tue 2/10/12
8	1.1.6	Camera calibration software completed	Mon 1/10/12	Mon 1/10/12
9	1.1.7.1	Develop asparagus detection software (part 1)	Tue 2/10/12	Sat 6/10/12
10	1.1.9	Develop asparagus location logging	Sun 7/10/12	Tue 16/10/12
11	1.1.10	Asparagus location logging completed	Tue 16/10/12	Tue 16/10/12
12	1.1.7.2	Develop asparagus detection software (part 2)	Wed 17/10/12	Thu 8/11/12
13	1.1.8	Asparagus detection software completed	Thu 8/11/12	Thu 8/11/12
14	1.1.11	Develop camera mounting system	Fri 9/11/12	Thu 15/11/12
15	1.1.12	Camera mounting system completed	Thu 15/11/12	Thu 15/11/12
16	1.1.13	Develop a mobile test rig	Fri 16/11/12	Thu 22/11/12
17	1.1.14	Mobile test rig completed	Thu 22/11/12	Thu 22/11/12
18	1.1.15	System testing & improvements	Sat 22/12/12	Wed 2/1/13
19	1.1.16	Obtain approval of performance	Wed 2/1/13	Wed 2/1/13
20	1.1.17	Asparagus cutting angle of approach software		
21	1.1.18	Asparagus cutting angle of approach software completed		
22	**1.2**	**Financial analysis**	**Fri 23/11/12**	**Fri 21/12/12**
23	1.2.1	Cost saving analysis	Fri 23/11/12	Sun 16/12/12
24	1.2.2	Alternate revenue streams analysis	Mon 17/12/12	Wed 19/12/12
25	1.2.3	Business Plan Development	Wed 19/12/12	Fri 21/12/12
26	1.2.4	Obtain approval of assumptions and analysis	Fri 21/12/12	Fri 21/12/12
27	**1.3**	**MEM requirements**	**Mon 26/11/12**	**Fri 22/2/13**
28	1.3.1	Video presentation submitted	Mon 26/11/12	Mon 26/11/12
29	1.3.2	Draft project report submitted	Fri 25/1/13	Fri 25/1/13
30	1.3.3	Final project report version 1 submitted	Fri 1/2/13	Fri 1/2/13
31	1.3.4	Updated final project report submitted	Fri 22/2/13	Fri 22/2/13

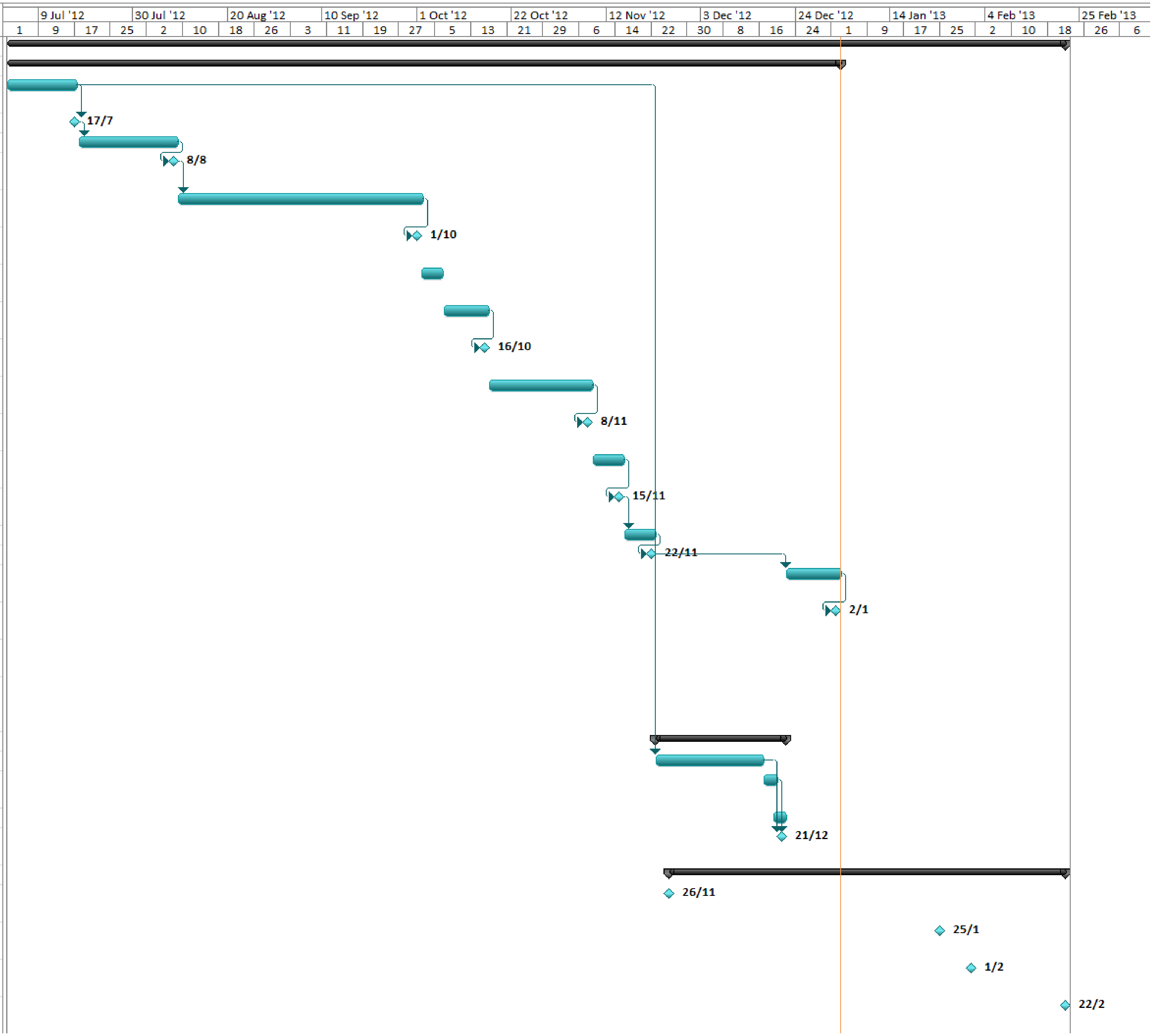

Figure 3.4.1) The project Gantt chart

4. Project Risks

Risk Level	Risk Value
Low	1 => 5
Moderate	6 => 10
High	11 => 15
Extreme	16-30

Table 4.1) The project risk categories

Risk Area	Impact (1 – 5)	Chance (1 – 5)	Risk Category (1 – 30)	Project Mitigation Plan
Time delays	5	3	15	The time set aside to write the final project report is relatively small due to work commitments, therefore these must be minimised.
Timely communication	4	2	8	Communication has been good to date, with no issues arising. This is still required as the final report will need checking by the client before final submission.
Authority	2	2	4	Only the project report requires completing so the impact of this has decreased.
Team input	2	2	4	To date all pieces of required feedback and information have been received very promptly, and there is now less input required.
Knowledge	2	2	4	Only the project report requires completing so the impact of this has decreased.
Project objectives	1	1	1	The client has agreed that the project objectives have been met so this risk is neglible.
Scope clarity	1	1	1	The client has agreed that the project objectives have been met so there is no longer

				a chance of the scope clarity changing.
Scope variations	1	1	1	The client has agreed that the project objectives have been met so there is no longer a chance of the scope changing.
Average			4.75	

Table 4.1) The project risk analysis

Most of the risks have changed since the last progress report. This is because the technical and financial project tasks have been completed and only the final project report remains.

5. Upcoming work

The task outlined in the table below is expected to begin tomorrow, 03/01/2013.

This task is going to require strong planning and time management due to full-time 12 hour shift work commencing for the student on Monday 07/01/2013. As well as this the student has a brother's wedding, a friend's wedding, and another compulsory event. Therefore available time needs to be planned and dedicated to the final project report, milestone 1.3.2.

WBS	Upcoming Tasks for next period	Forecast Completion
1.3.2	This task is due to start tomorrow, 03/01/2013.	25/01/2013

Table 5.1) Upcoming tasks

C. Milestone Reports

Milestone 1.1.2 Report

1. Milestone Summary

WBS	Task Name	Scheduled Finish Date	Realisation Date	Realisation Summary
1.1.2	Design Decisions Confirmed	17/07/2012	15/07/2012	Completed slightly ahead of schedule

Table 1.1) A summary of the milestone including important dates

2. Milestone Aim

Trends shall be identified from several NZ asparagus growers based on the problem descriptions identified by the client. These trends will relate to what level of functionality the automated harvester should have, what functions are more important than others, and what the required harvest accuracy is.

3. Milestone Process

An online survey was created and sent to TODO New Zealand asparagus growers. Six replies were received from a range of asparagus growers. The questions in the survey were designed to give an indication of required functionality. No questions were asked with regards to how much growers would be willing to pay as information received could be very unreliable and detailed cost figures are available from the project sponsor.

The survey was made as brief as possible to increase the number of responses while having enough detail to reach accurate conclusions. The questions asked were:

1. What is your name?
2. What is the name of your asparagus growing business?
3. In terms of functionality, how important is it that an automated asparagus harvester is autonomous? (Does not require a driver/operator) (Keep in mind extra functionality incurs extra design and manufacturing costs)
4. How important is it that an automated asparagus harvester stores and recalls data about the size of asparagus spears throughout paddocks to show high and low producing areas?
5. How important is it that an automated asparagus harvester identifies the quality of asparagus spears (eg. domestic/export) before sorting them into appropriate storage crates?
6. How important is it that an automated asparagus harvester can sort spears into crates according to the size (Small/Medium/Long and/or Short/Medium/Long)?
7. How important is the tradeoff between speed and accuracy in an automated asparagus harvester?
8. Is there anything else you would like to add?

Apart from questions 1, 2, 7, and 8 the survey respondents had the following options:

- Very unimportant

- Unimportant
- Neither unimportant or important
- Important
- Very important

The above responses were allocated quantitate figures ranging from 1 through to 5.

Question 7 had the following options for required asparagus identification accuracy which were allocated figures ranging from 2 through to 5:

- I want at least half of the asparagus spears picked (50%+) so that the machine can travel very fast.
- I want a moderate percentage of asparagus spears picked (80%+) but want the machine to travel moderately fast.
- I want a high percentage of asparagus spears picked (95%+), and am willing to sacrifice the rest (<5%) in order for the machine to travel slightly faster.
- I want every asparagus spear picked, no matter how slow the machine is.

The results were then graphed to provide an easier interpretation of the data.

4. Milestone Results

Six responses were received from the TODO queried asparagus growers. One respondent provided very different results to the other five. This is because he was a smaller grower therefore automated asparagus harvesters would not provide the benefits to him that they would to other growers. Where individual questions provided a large variability in results further research was performed to identify why the variability existed.

The following graphs display the data received for questions 3 to 7:

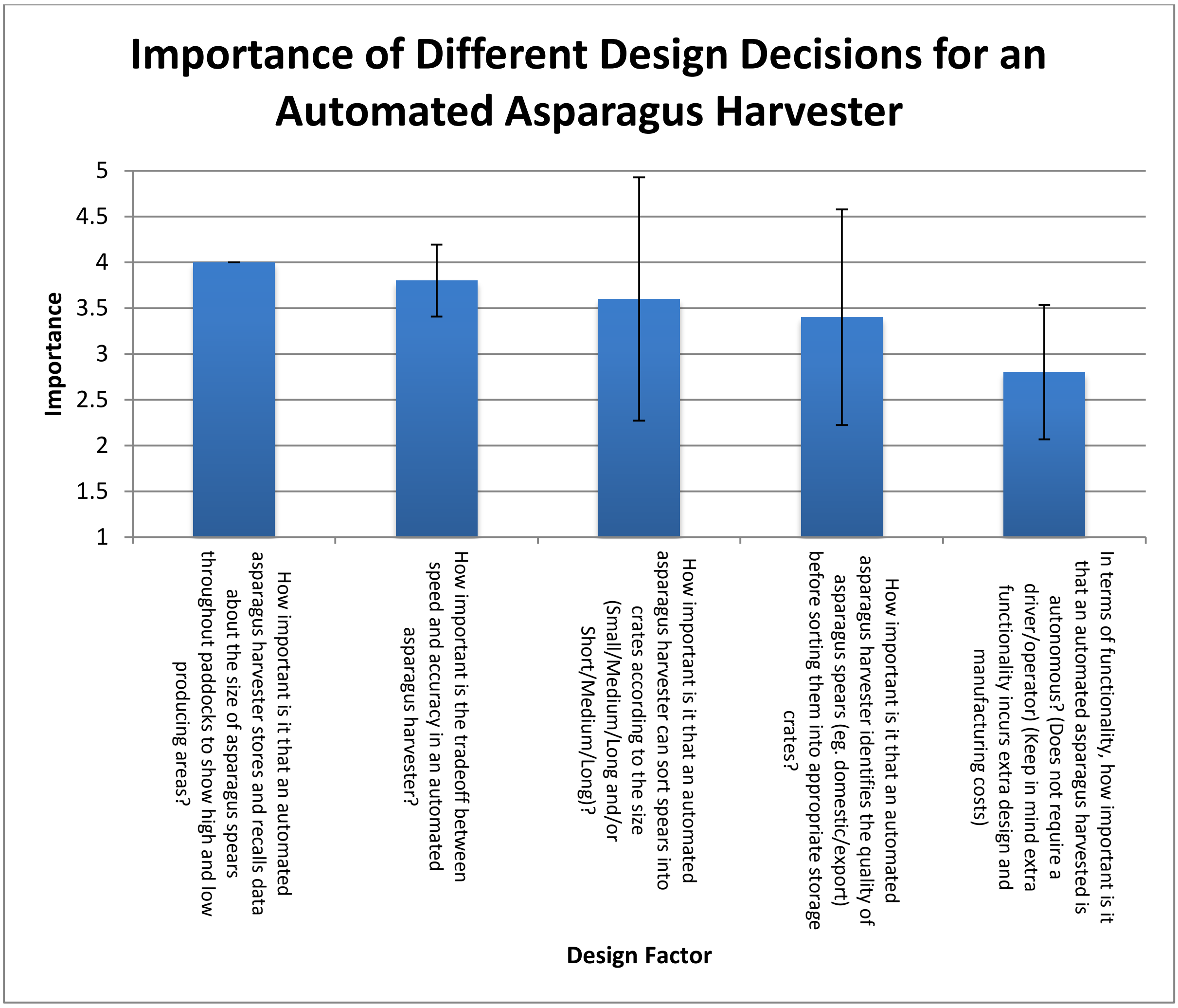

Figure 4.1) The formatted survey results excluding the identified outlier

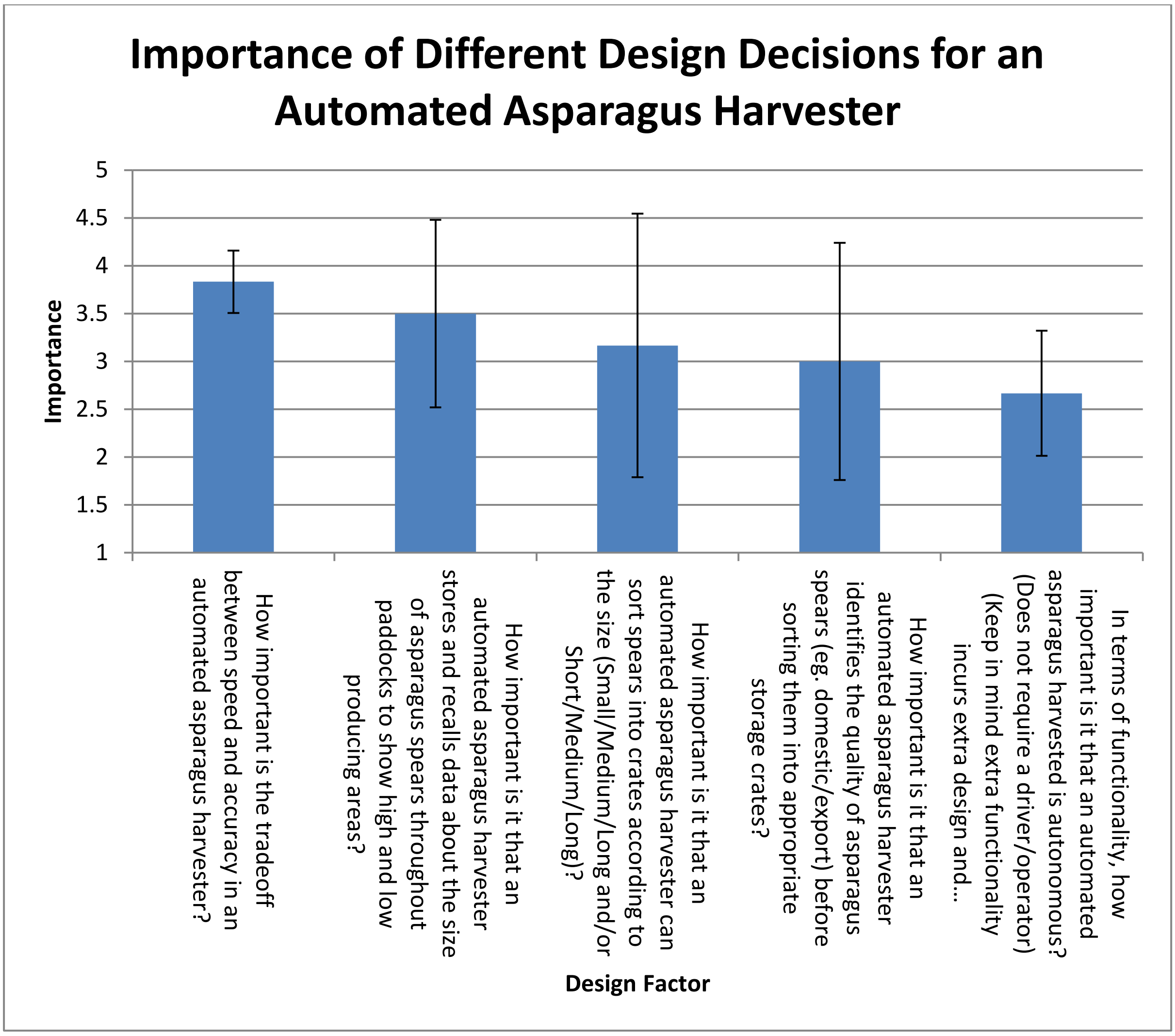

Figure 4.2) The formatted survey results including the identified outlier

The following results were received for question 8, and these directly quoted from the survey:

- Freshness and Cost is really important to how business. A machine is only as fast as the slowest human. A good machine needs great operators. Thanks Simon
- I largely pick for processing so sorting is not as important to me as a local/exporter grower. Good Luck
- Minimising collateral damage to spears neighbouring the target spears is important. High levels of collateral damage is one reason why earlier machines have failed

The following response is from the grower identified as an outlier:

- The machine must be affordable to smaller growers and be able to work at night. It must be able to be replicated so multiple rows can each have their own cutting head, and be mounted on the same machine.

5. Milestone Conclusions

There are relatively large confidence intervals for the received results, however trends are identifiable. A larger number of survey respondents would reduce the confidence interval however there is a relatively small number of asparagus growers within New Zealand.

Asparagus growers feel that data relating the size of asparagus spears to their location in a paddock is important. This data is to give an indication of high and low producing areas therefore with regards to the location of asparagus spears the accuracy required is high but not precise.

Asparagus growers want a high accuracy of asparagus spears picked, but the machine must be able to travel at a reasonable speed. Therefore an asparagus harvesting success rate of 95% is the minimum acceptable level.

Some growers would like the machine to sort asparagus spears according to their size but domestic growers do not see this as being as important. Further research revealed that differentiating skinny asparagus from all other asparagus was important here rather than a differentiating a wider range of sizes.

It is neither important nor unimportant that automated asparagus harvesters identify the quality of asparagus spears. Further research revealed that large asparagus pack houses have existing systems that identify the quality of asparagus spears therefore this process was not required in the field.

An automated asparagus harvester is not required to be autonomous. If it is relatively easy and inexpensive to make it autonomous then this should be implemented, however adding an operator does not concern asparagus growers.

6. Milestone Success

This milestone met the requirements of determining what design features were required in an automated asparagus harvester. There is enough information to continue with the project, and there is a clear technical direction.

Milestone 1.1.4 Report

1. Milestone Summary

WBS	Task Name	Scheduled Finish Date	Realisation Date	Realisation Summary
1.1.4	Background research completed	08/08/2012	03/08/2012	Completed ahead of schedule

Table 1.1) A summary of the milestone including important dates

2. Milestone Aim

Papers and patents that relate to automated asparagus harvesters shall be identified and researched. These papers and patents will relate to every subsystem including those not included in the development scope of this project. Therefore the research will cover the asparagus location subsystem, the navigation subsystem, the asparagus cutting and collection subsystem, and the asparagus storage subsystem.

3. Milestone Process

At the same time as this milestone the MEM Intellectual Property Law assignment had been created and not yet due. Therefore this milestone was completed through completing the assignment as I chose to do it on automated asparagus harvesters and the assignment was very comprehensive.

4. Milestone Results

See the attached document "IP Law Assignment (Marked)" for the results from this milestone.

5. Milestone Conclusions

No systems were discovered that perform the job of automated asparagus harvesting as well as is currently required by NZ growers.

There were no patented subsystems that could cause conflicts upon entering the market either.

Also the proposed design continues to be the most viable known approach to solving the problem of automated asparagus harvesting.

6. Milestone Success

The aims of the milestone were met, with a large amount of research conducted and intellectual property identified. This research discovered what methods have been used in the past, and what alternate methods have been explored (as long as it had been published or made publically available).

Milestone 1.1.6 Report

1. Milestone Summary

WBS	Task Name	Scheduled Finish Date	Realisation Date	Realisation Summary
1.1.6	Camera calibration software completed	01/10/2012	28/09/2012	Completed slightly ahead of schedule

Table 1.1) A summary of the milestone including important dates

2. Milestone Aim

The camera system shall able to perform self-calibration, before reconstructing points to within an acceptable accuracy. The acceptable accuracy will be determined by both the Project Manager and the asparagus growers questioned in milestone 1.1.2. This includes the incorporation of the software into a graphical user interface (GUI) to streamline the process.

3. Milestone Process

Camera calibration procedures were researched as part of milestone 1.1.4, however the initial calibration method was still found to be the most suitable camera calibration method known. This camera calibration method was familiar to the student because he was given part of the software for a previous project written in the MATLAB computer programming language. The reason this calibration method was chosen is because it is a fast and easy method to calibrate the cameras before transforming the calibration parameters into a robotic arms coordinate system.

For this project different computer programming languages were explored as the automated asparagus harvester could be travelling very quickly and require the software to make fast decisions and calculations. C++ was identified as the most suitable language, because it is efficient and fast at performing image processing algorithms.

The calibration process was studied and learned while writing it in C++. It is a complex procedure that involves a precision manufactured calibration cube that has been made according to dimensions that the student thought suitable, and a series of image processing algorithms to locate the corner and dot centre points, see figure 3.1. These detected points are reconstructed back onto the cube and compared with the detected points to calculate the accuracy. These points are then used to calculate the cameras parameters (intrinsic and extrinsic) and thus complete the calibration.

A Graphical User Interface (GUI) was created to assist in calibrating the cameras while also assisting the user in determining what individual algorithm was failing if the entire calibration failed. The robotic arm to harvest and collect the asparagus spears is not in the scope of this assignment, so the functionality required to transform the coordinate system into one appropriate for use with a robotic arm has not been implanted but appropriate GUI inputs and software functions have been reserved for this.

The software has been written as modular as possible, so if any algorithms or GUI components require changing this can be done relatively easily. Also because there is a chance of this project creating another project all software has been written with comments explaining what is happening so that future developers can understand the software as quickly as possible.

Figure 3.1) The calibration cube with detected and reconstructed points of interest.

4. Milestone Results

The speed at which the calibration is completed is not important, as once the cameras are calibrated they do not require recalibration unless the cameras or robotic arm are shifted. However the speed of calibration in this project using the C++ programming language appears to be faster than the MATLAB calibration. A comparison has not been performed due to software licences, however this is going to be performed at a later date. If this observation is true then C++ has been an appropriate choice and the asparagus detection software should also be fast if written correctly.

The accuracy being achieved with this calibration software is also very promising. The average errors are very small, however there is variability in this accuracy. The maximum errors appear relatively large however they are will being measure in pixels so the accuracy required for this project is still easily being achieved.

Errors (pixels)	**Test Image 1**		**Test Image 2**	
Mean Error (x, y)	0.001252	0.001355	0.000483	0.001362
Max Error (x, y)	0.765656	1.14702	-1.14832	0.934254
Error Standard Deviation	0.346782	0.478038	0.382166	0.42431

Table 4.1) The accuracy of the camera calibration software using two test images

More testing is required, however this will more accurate once the camera mounting system has been developed so the cameras are being calibrated as they would in normal operating conditions.

Qt was used to develop the GUI. This tool was difficult to learn at first, however the functionality within Qt was acceptable and the GUI developed is easy to use and easy to modify is necessary.

5. Milestone Conclusions

The camera calibration software has been developed, and the use of C++ as a programming language appears appropriate however further testing is required to validate this.

Some testing has been performed on the effectiveness of this calibration method, and results are promising however further testing is required later in the project under normal operating conditions.

The GUI created is easy to use, with little user input required.

6. Milestone Success

The cameras are able to be easily and accurately calibrated. This process has also been incorporated into a GUI that can easily be understood and modified if necessary.

Milestone 1.1.8 Report

1. Milestone Summary

WBS	Task Name	Scheduled Finish Date	Realisation Date	Realisation Summary
1.1.8	Asparagus detection software completed	8/11/2012	9/11/2012	Completed slightly behind schedule

Table 1.1) A summary of the milestone including important dates

2. Milestone Aim

The development of software that makes decisions on how to pick asparagus spears in any typical orientation with a range of asparagus spears surrounding the target area, based on a given set of rules established by prior knowledge shall be developed. This software shall assume that the asparagus can be harvested by a mechanism approaching from any position and any angle surrounding the asparagus spear.

3. Milestone Process

At the beginning of this milestone I had a general idea on how the final test rig would be constructed, including how the cameras would be arranged within this. I also assumed that green LEDs would provide the best illumination of asparagus spears without illuminating a large amount of other objects.

Images were captured using a range of different coloured LEDs at different brightness levels to illuminate the asparagus spears including:

- Red.
- Yellow.
- Green.
- Blue.
- White.

These images were grey scaled within software by using the inbuilt openCV function as well as retrieving only the red, green, and blue colour channels to observe what method illuminated the asparagus spear the best while supressing other objects in the images. Green LEDs illuminated the asparagus spears the best with blue LEDs illuminating the bracks[1] on the asparagus spears the best. This testing was performed through manually observing at the images after grey scaling and making decisions rather than quantitative testing.

With green and blue LEDs focused on a single asparagus spear some software was developed to detect a single asparagus spear from an image. With this software developed the LEDs were tested in a range of positions with different illumination levels. Rows of LEDs were positioned:

- Vertically on both sides of a camera, see figure 8.1.

[1] The bracks are the purple coloured triangular parts on asparagus spears.

- Horizontally above a camera, see figure 8.2.
- Vertically below a camera, see figure 8.3.

The performance of the software using these different LED arrangements was tested to determine what performed the best.

The next step was to calculate the length of the asparagus spear to confirm that it is ready to be harvested, and then calculate the position of the asparagus spear that can then be passed to a robotic arm to cut and harvest the asparagus spears. Because the design of the test rig environment and illumination method had only just been confirmed and not yet constructed it was not possible to have two cameras as well as the LEDs working in conjunction to detect asparagus spears. Therefore the cameras were calibrated using the software developed in milestone 1.1.6, and when images were then captured of asparagus spears the background of the image had to be manually erased using Microsoft paint. This allowed the 3D software to be developed and tested.

As part of this milestone more than one asparagus spear was meant to be able to be present within in the image before the software locates each one individually however this was not possible. This is because the LEDs provided to narrow of an illumination, and the test rig suitable for this testing has not been constructed yet. Therefore this will have to be developed within task 1.1.15, "System Testing and Improvements". Wide angle LEDs have been ordered and have since arrived so these will be tested as part of task 1.1.15.

The location, length and size testing was not able to be tested thoroughly because there is no robotic arm or precision measuring tools present. Therefore several asparagus spears were placed in a straight line, before the length and size of each was calculated using the software. The distance between each spear was also calculated, and each of these measurements were compared to the measurements obtained using a standard ruler.

4. Milestone Results

The software performs well when there is a single asparagus spear in the image with good illumination. There was no way to reliably confirm the accuracy of the software, however initial results using a ruler showed that the software and ruler were accurate within approximately 5mm for the length and distance between asparagus spears. This is not accurate enough, however testing was not able to be thoroughly performed since the cameras were not mounted firmly and it was impossible to measure the asparagus spears without bumping the cameras. The size calculations of the asparagus spears were also not accurate enough, with an accuracy of only 4mm over the width of a 16mm asparagus spear. This needs to be better tested and the software improved, but time has been allowed for this in task 1.1.15. The results of the tests performed are not included in this report as they were conducted scientifically enough and are going to be repeated more scientifically in task 1.1.15.

From the work within this milestone the design of the test rig was confirmed including what illumination was necessary and in what arrangement. The position of the cameras have been changed as testing has shown that the cameras need to be mounted lower than initially thought in order to improve the accuracy. The cameras cannot be too low however, as they need to maintain a good view of three sides of the calibration cube to provide an accurate calibration. Wide angle LEDs are also required and these will be positioned alongside each camera. The illumination of these LEDs are currently fixed, however this may be varied in the future if the asparagus detection is not performing accurately enough.

Because of the restrictions described the milestone was not met, however after task 1.1.15 has finished this the goals of this milestone may have been met.

5. Milestone Budget

This milestone was finished under budget. The materials cost slightly less than expected, and the time required was also slightly under budget. This led to the overall budgeted cost of work performed (BCWP) being less than the budgeted cost of work scheduled (BCWS). A new laptop was not purchased, instead the client has supplied a laptop that should be suitable for the testing to be performed.

Hours		Materials		Budgeted Cost of Work	
Budgeted	Actual	Budgeted	Actual	Scheduled (BCWS)	Performed (BCWP)
188	185.2	$1453.04	$1386.07	$6,695.35	$6,550.30

Table 5.1) An actual and budgeted breakdown for the costs of this milestone

6. Milestone Conclusions

The cameras are able to detect a single asparagus spear but not more than one.

The cameras show potential for accurate asparagus spear length, size, and position calculations.

The design of the test rig and camera mounts were confirmed through the testing performed.

7. Milestone Success

This aims of this milestone were not fully met. These aims may be met at the conclusion of task 1.1.15.

8. Milestone Images

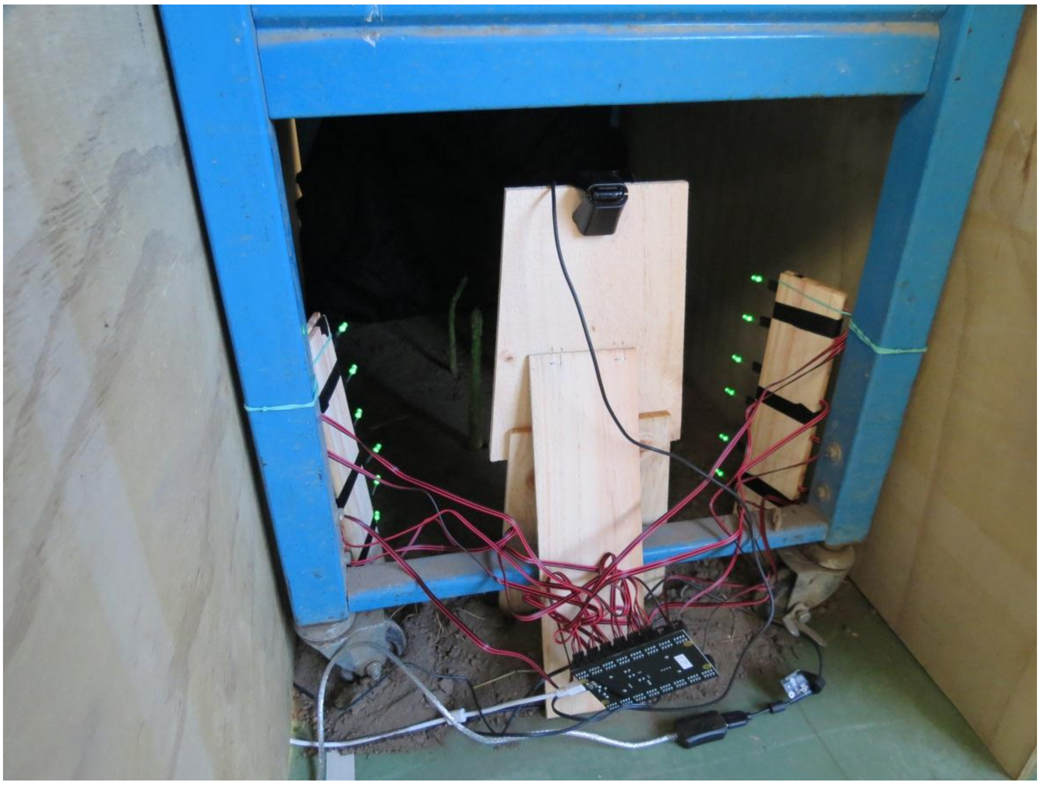

Figure 8.1) The asparagus detection software development setup with the LEDs providing illumination from alongside the camera

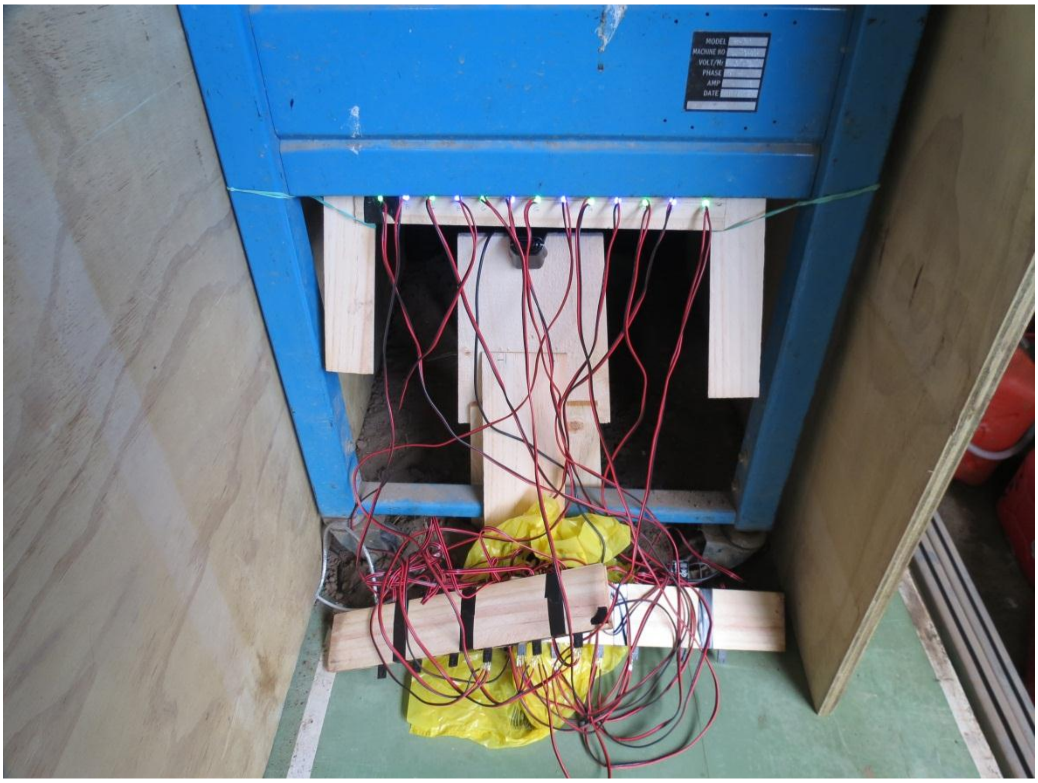

Figure 8.2) The asparagus detection software development setup with the LEDs providing illumination from above the camera

Figure 8.3) The asparagus detection software development setup with the LEDs providing illumination from below the camera

Milestone 1.1.10 Report

1. Milestone Summary

WBS	Task Name	Scheduled Finish Date	Realisation Date	Realisation Summary
1.1.10	Asparagus location logging completed	20/10/2012	16/10/2012	Completed ahead of schedule

Table 1.1) A summary of the milestone including important dates

2. Milestone Aim

Approximate GPS locations shall be able to be saved for every detected asparagus spear, and later retrieved. The GPS locations do not need to be precise, instead accurate enough to give an indication of the size distribution of asparagus spears throughout fields.

3. Milestone Process

Two separate USB GPS-units were purchased for software development. By having two different GPS units the performance of each could be compared. These GPS units were a “Garmin GPS 18 OEM” and a “Globalsat BU-353”.

The first step was to get the computer recognising the GPS units. The Globalsat GPS was very easy to setup, and the included cd made the process of assigning the GPS to a communication port on the computer very easy. The Garmin GPS was more difficult to setup, and it required third-party software to assign the GPS to communication port on the computer. The third-party software used was “Franson GpsGate” and this had to be running while the GPS was to be used in the Asparagus Harvesting System.

Once the GPS had been assigned to a communication port the location data needed to be retrieved. This was relatively easy for both GPS units, as the data stream was in the standardised NMEA format. The most difficult component of reading the data was when the message contained garbage data, as this required filtering out.

The location and size of asparagus spears needed to be saved so they could be later retrieved. This required setting up the functionality for saving individual asparagus spears with the appropriate information. Because there will be a large number of asparagus spears saved each day for each farm each asparagus spear needs to take up as little data space as possible while still storing enough data to be useful in the future. Every day of harvesting for each farm is saved in a unique file “.aspharv”, and this file automatically updated as the system runs. This file can be loaded into the system later for continued harvesting. The cross-sectional area of asparagus spears defines the size of the asparagus spear, but this figure is not easy to interpret so an easier method is required. Therefore a maximum cross-sectional area all asparagus spears has been defined and every asparagus spear is given a size between 0 and 100 where 100 is the largest possible size, and 0 is infinitesimally small. This makes it easier to interpret the harvesting data.

When the custom asparagus harvest files are loaded the software displays a range of information which includes; the number of asparagus spears detected, the average asparagus spear size, the standard deviation of asparagus spears, and the accuracy of the camera system. The accuracy of the camera system will be implemented in milestone 1.1.8.

Map files are automatically saved and updated for every harvesting day and farm. This map file is in the ".kml" format so it can be loaded into Google Earth. The markers for each asparagus spear are circular and the colour is directly proportional to the size. The colour green equals an asparagus spear size of 100, and red equals an asparagus spear size of 0. The colours then vary from green to red for the in-between sizes. This allows easy to interpret information for the size distribution of asparagus spears throughout asparagus paddocks.

When the work performed was shown to the client he did not want the data from all asparagus spears shown in one map file, rather the ability to only save certain size asparagus spears was desired. Therefore a custom map file saver was implemented that allows the user to save asparagus spears between two size limits, or between two percentiles.

4. Milestone Results

The Globalsat GPS performed much better than the Garmin GPS. This is because the Globalsat unit connected to Satellites much faster, and was much easier to get working. Also the updates from the GlobalSat GPS were received closer to realtime that the Garmin GPS updates. The accuracy of both units appeared very similar, however this is hard to quantify since GPS units have an absolute error unless they are the costly Real Time Kinematic (RTK) satellite systems.

The system coped with large amounts of asparagus spears stored. The software did not crash when there were 21,000 asparagus spears being tracked, however the system did slow down considerably. This is acceptable since the project is a feasibility analysis, and testing will not require that many asparagus spears stored. When the system had harvested a certain number of asparagus spears they could all be saved before automatically starting a new file. For these 21,000 asparagus spears the raw data file ".aspharv" was 144mb, and the map file was 151mb.

The custom map file saving performed well and the client is very happy. This functionality performed so well that several a major benefit became more apparent, which is selective breeding from top-producing asparagus plants. This will be beneficial to both asparagus growers and plant breeders.

5. Milestone Budget

This milestone was met under budget. The materials cost more than expected, however the time required was much less than expected. This led to the overall budgeted cost of work performed (BCWP) being less than the budgeted cost of work scheduled (BCWS).

Hours		Materials		Budgeted Cost of Work	
Budgeted	Actual	Budgeted	Actual	Scheduled (BCWS)	Performed (BCWP)
94	76.4	$100.00	$137.16	$2,721.15	$2,267.54

Table 5.1) An actual and budgeted breakdown for the costs of this milestone

6. Milestone Conclusions

The functionality of adding a GPS unit is very important to the client. The performance of the GPS units was at an expected level. The complexity of the GPS was much less than expected, as shown by the software development taking a much shorter time than expected.

The ability to save asparagus spears into a file for later retrieval was also a good decision.

7. Milestone Success

The milestone was met, and the client was very happy with the results.

Milestone 1.1.12 Report

1. Milestone Summary

WBS	Task Name	Scheduled Finish Date	Realisation Date	Realisation Summary
1.1.12	Camera mounting system completed	15/11/2012	15/11/2012	Completed on schedule

Table 1.1) A summary of the milestone including important dates

2. Milestone Aim

One or more cameras shall be firmly mounted in place in a mounting system that can easily be attached to an automated harvesting rig. The exact configuration of this mounting system will depend on the results from milestone 1.1.8.

3. Milestone Process

Two Logitech C910 cameras are being used for this project, and these required a mounting method that allows for easy adjustments throughout the testing process. These cameras have sloped top and bottom edges which introduces another factor rather than simply clamping them, see figure 3.1. A basic design was drawn on a whiteboard but this did not have any dimensions or detail attached, see figure 3.2. It was not known how the top and bottom sections of the “clamp” were going to fasten onto the camera, however the other known components started being fabricated in the workshop. It was not until the method for attaching the entire mount to the slotted rail that the entire design was finalised. The slot method could also be used to attach the top and bottom sections of the “clamp”, and this would also make it easier to hold the camera in place while fastening, see figures 3.3 and 3.4. Once the mounting systems were constructed a camera was inserted into each, and both cameras were firmly held without damaging either camera.

With the camera mount constructed the lighting system also required mounting, and from the results of milestone 1.1.8 this lighting system should work in conjunction with the location of the cameras. Therefore it made sense to construct a lighting system mount immediately after the camera mount. The lighting system is going to consist of four vertical strings of LEDs, with one on each side of either camera. Because the cameras are going to be mounted in the corners of the test rig there is a chance of the lighting systems not fitting due to the side walls. Because of this a model was constructed using the Computer Aided Design (CAD) software Solidworks. The constructed camera mount was modelled, before the proposed test rig design was also modelled. By seeing the proposed model a lighting mount was easily designed and produced using Solidworks. As expected the lighting mount did not fit using the standard steel that was available for construction. Some modifications were made to the design before it could fit within the test rig, and these modifications were able to be reproduced within the workshop, see figures 3.5 to 3.7.

With the model for the lighting system mount modelled using CAD software it was very easy to produce technical drawings. These technical drawings helped in a much faster and more accurate fabrication process than when there were no technical drawings for the camera mount. Two lighting mount systems were constructed and tested that they work in conjunction with the camera mount, see figure 3.8.

The construction of lighting system was decided in task 1.1.7, and these required fabrication. Using veroboard, 52 wide-angle blue and green LEDs, the Phidgets Led64 kit, and 52 meters of cable this was all soldered in place. This design also allows for easy modifications to be made if necessary, see figure 3.9. These were not attached to the lighting mount system as this will not require a large amount of time and it will be easier once the test rig has been constructed.

Figure 3.1. A side on view of the Logitech C910 cameras being used for this project [2]

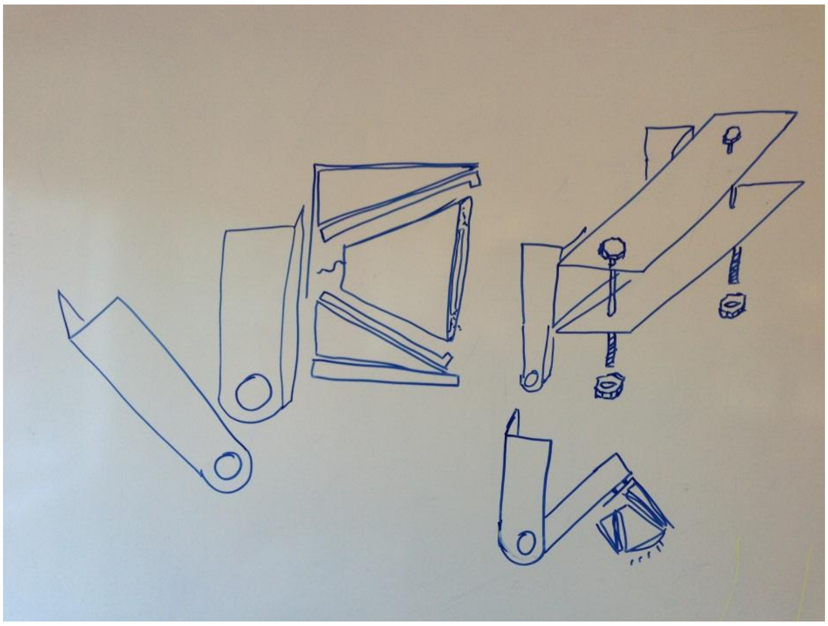

Figure 3.2. The first concept design for the camera mount

[2] http://www.logitech.com/en-au/webcam-communications/webcams/6816

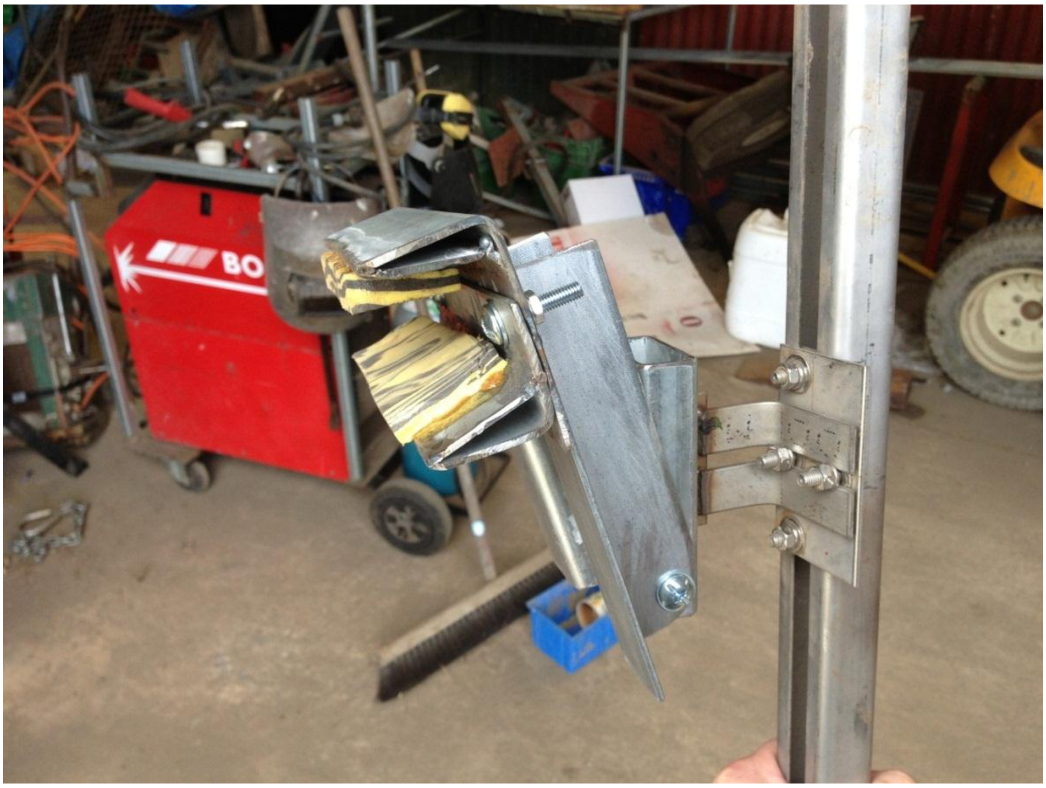

Figure 3.3. A complete camera mount

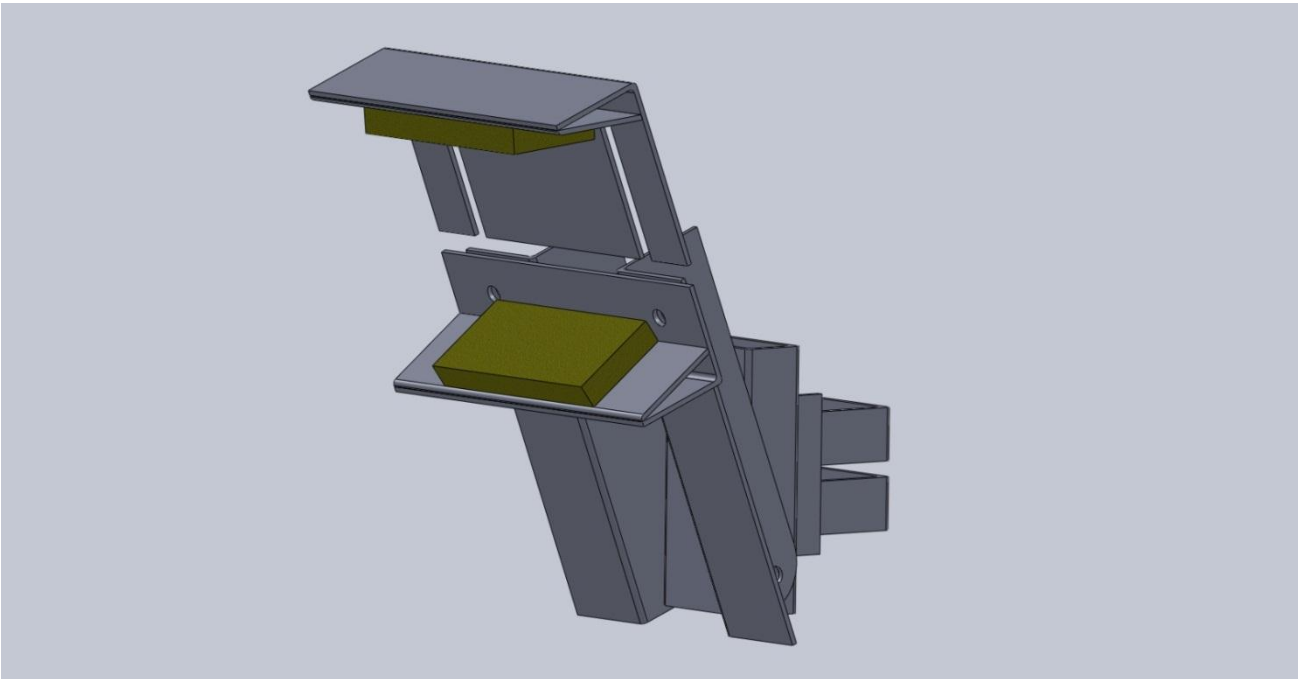

Figure 3.4. A graphical representation of a camera mount assembly

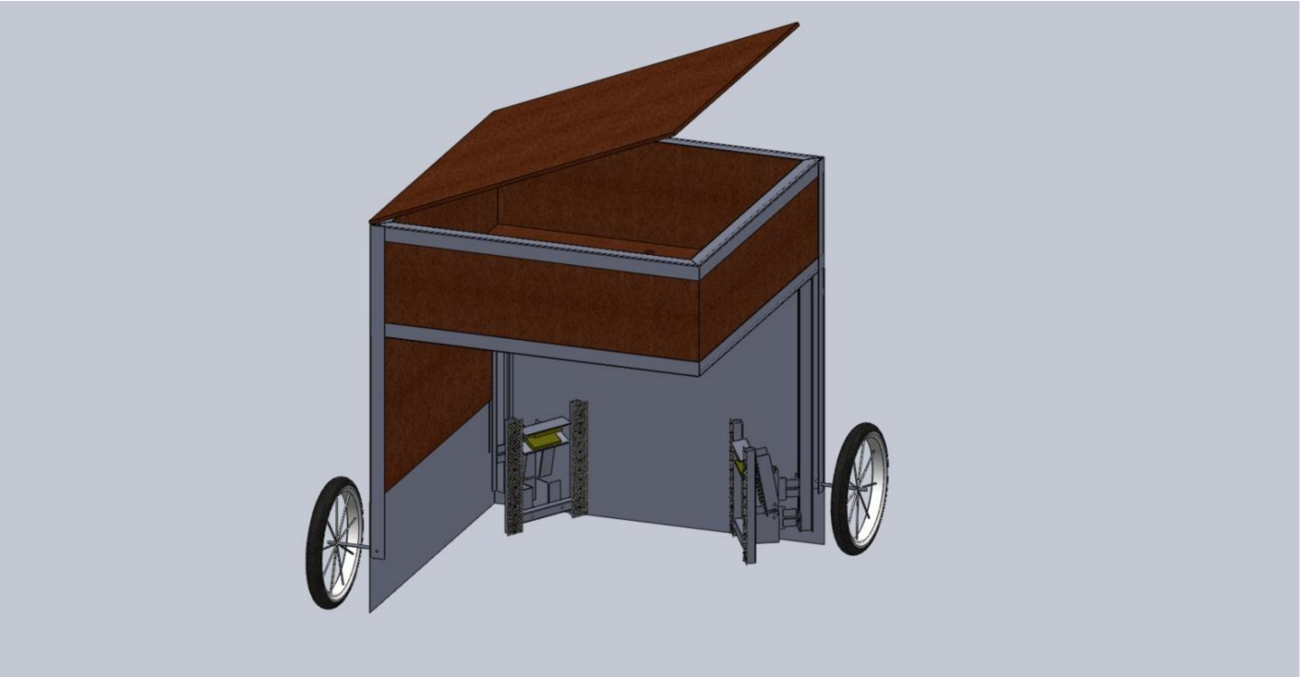

Figure 3.5. A graphical representation of the current test rig design with two sides hidden to allow internal viewing

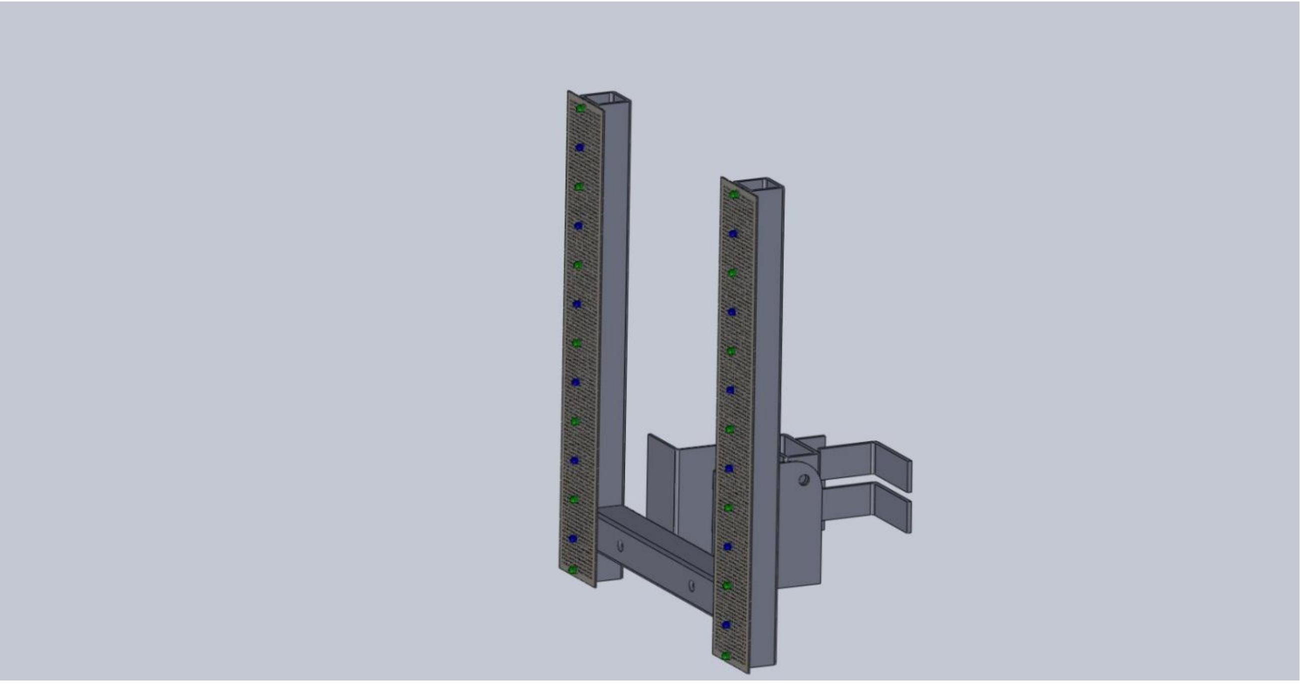

Figure 3.6. A lighting mount system model

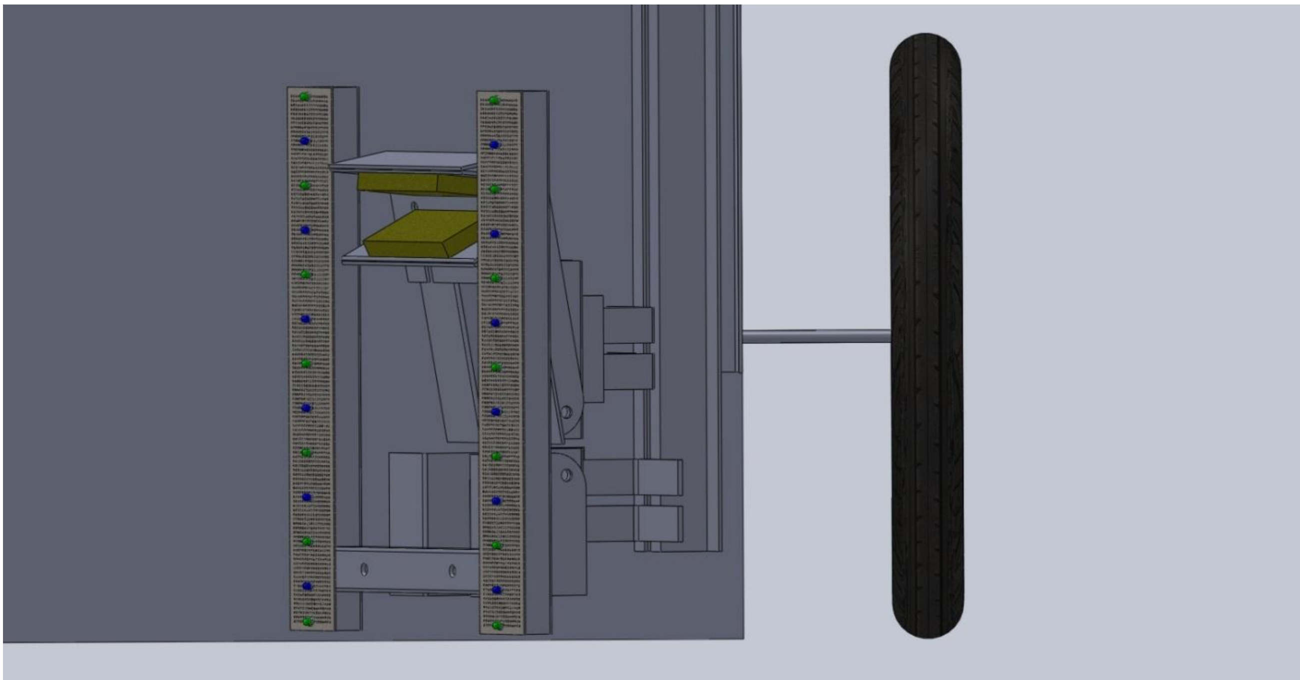

Figure 3.7. A camera and lighting mounting systems within the test rig model

Figure 3.8. A constructed camera and lighting mount

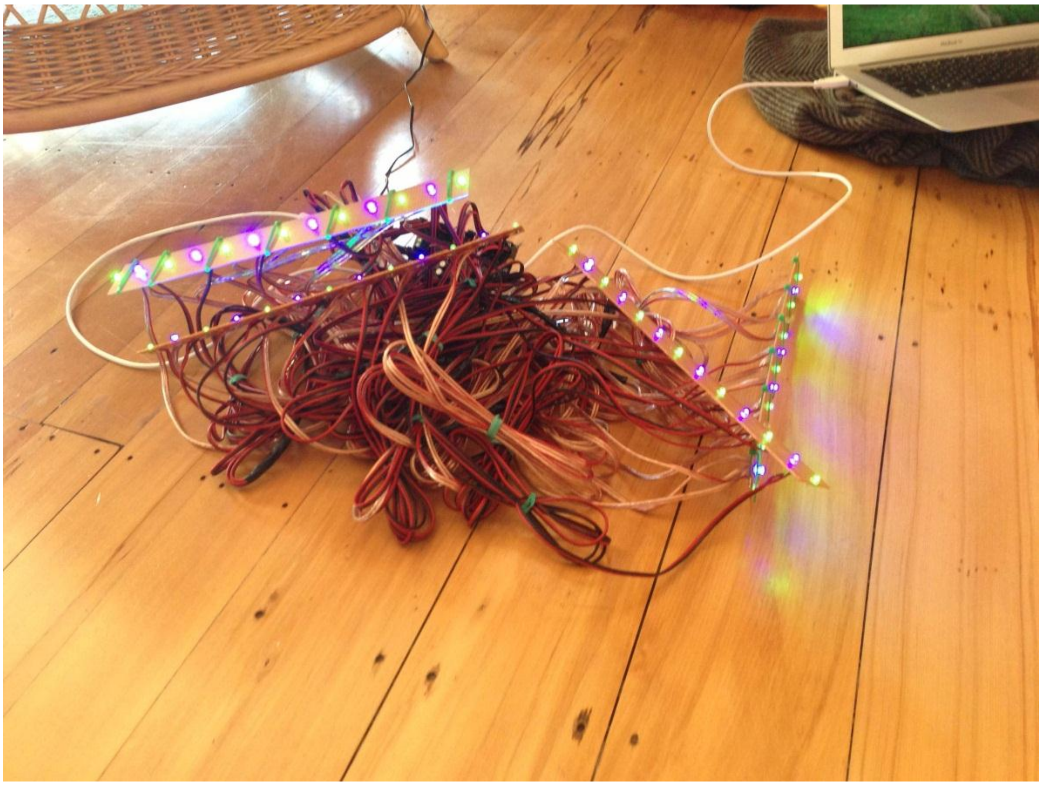

Figure 3.9. The assembled lighting system

4. Milestone Results

The cameras were able to be firmly mounted in their designed mounting systems. The cameras could be adjusted up and down, as well as the angle at which they face the ground at. There is no sideways adjustment possible, however this is not required of the cameras. If the cameras need to be lower with respect to the height of the lighting system, the mount can be rotated so the camera hangs below where the mounting system is attached to the rail, see figure 3.7.

The lighting system is able to be securely mounted alongside the cameras. There is the ability to adjust the height of the lighting system, as well as the angle at which it faces the ground. It is not expected that the lighting system will require adjusting in any other directions or angles.

The lighting system is functional, and there is the ability to make modifications relatively easily. The veroboard means that if an LED stops working, it can easily be removed through de-soldering the connections and soldering a new LED in place. The 1m extension lengths of wire attached to each LED will be long enough to allow the lighting systems to be mounted in place while the LED controller is located within the top compartment of the test rig, figure 3.5.

5. Milestone Budget

This milestone was met under budget. The materials cost slightly more than expected, and the time required was slightly less than expected. This led to the overall budgeted cost of work performed (BCWP) being less than the budgeted cost of work scheduled (BCWS).

The previous task within the project went 1 day over schedule which impacted on the starting date for this project. This task was scheduled for 47 hours over 6 work days, however it was completed using the remaining 5 scheduled days. This is because the project cannot afford to fall behind schedule.

Hours		Materials		Budgeted Cost of Work	
Budgeted	Actual	Budgeted	Actual	Scheduled (BCWS)	Performed (BCWP)
47	46.7	$150.00	$153.48	$1,460.58	$1,455.69

Table 5.1) An actual and budgeted breakdown for the costs of this milestone

6. Milestone Conclusions

The designed camera and lighting mounts are very strong and should perform their required tasks well. The decision to use veroboard for the lighting system was

7. Milestone Success

The milestone was met, and the client was very happy with the results.

Milestone 1.1.14 Report

1. Milestone Summary

WBS	Task Name	Scheduled Finish Date	Realisation Date	Realisation Summary
1.1.14	Mobile test rig completed	22/11/2012	22/11/2012	Completed on schedule

Table 1.1) A summary of the milestone including important dates

2. Milestone Aim

A test rig that can be mobilised around asparagus fields undertaking the camera system and data logging tasks shall be constructed. If the camera mounting system in milestone 1.1.12 is modified, this test rig should not require major modifications.

3. Milestone Process

The test rig had been designed using the Computer Aided Design (CAD) software Solidworks as part of task 1.1.11, develop a camera mounting system. This made generating technical drawings very easy, and the construction time was decreased as a result.

After the drawings were produced the size of the test rig was increased from 0.9m wide and long to 1m. This was to make it easier to push through asparagus paddocks without while not walking over asparagus. Bicycle wheels were sourced from a local store and it was decided that tyres were not required to perform the task of being mobile around the sand based asparagus paddocks.

Black cotton curtains with white backing have been made to drape down from each side wall, as well as at the front and back. There was a large chance of light entering the test rig area with only one curtain at the front and back, so an additional row was added to each through extending a rail, see figure 3.2.

The inside of the test rig and both the camera and lighting mounts were painted matte black. This is to prevent any unwanted reflections and improve the illumination of only the asparagus spears, see figure 3.3.

The camera and lighting mount rails were extended in from the edges of the test rig, see figure 3.2 and 3.4. This was to position the camera closer to the asparagus spears for increased accuracy however the lighting boards may now be too narrow, and come into contact with asparagus spears while testing.

Two holes were drilled to allow the camera, lighting, and infrared sensor cables to connect to the required components in the storage area, see figure 3.5. These holes each had a small section of curtain made so that no light would enter through them.

The constructed test rig was transported to an asparagus paddock to test that its size was suitable for the width of the asparagus rows, and that it could easily be pushed along, see figure3.6. The curtains were not made at this stage so the lighting system could not be tested, however this will be performed as part of task 1.1.15, system testing and improvements.

A 12V car battery and a 300watt pure sine-wave inverter supplies continuous power to the test rig for the laptop and other electronics. This was chosen because it is relatively cheap, and does not vibrate like generators.

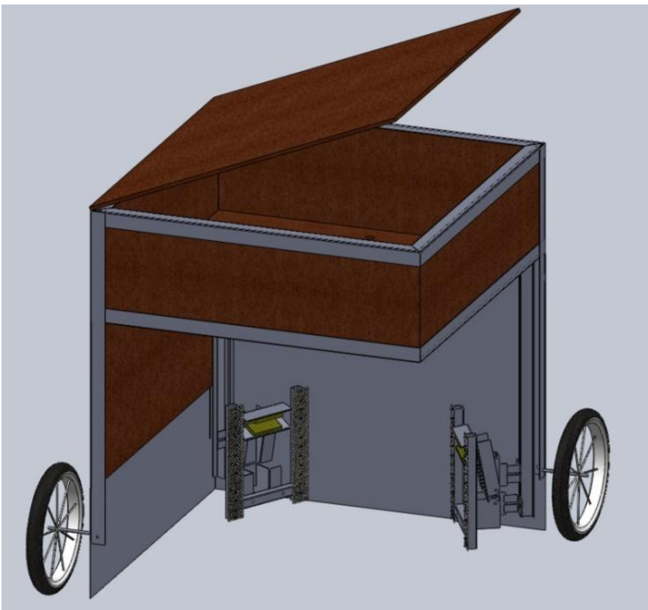

Figure 3.1. A graphical representation of the original test rig design with two sides hidden to allow internal viewing

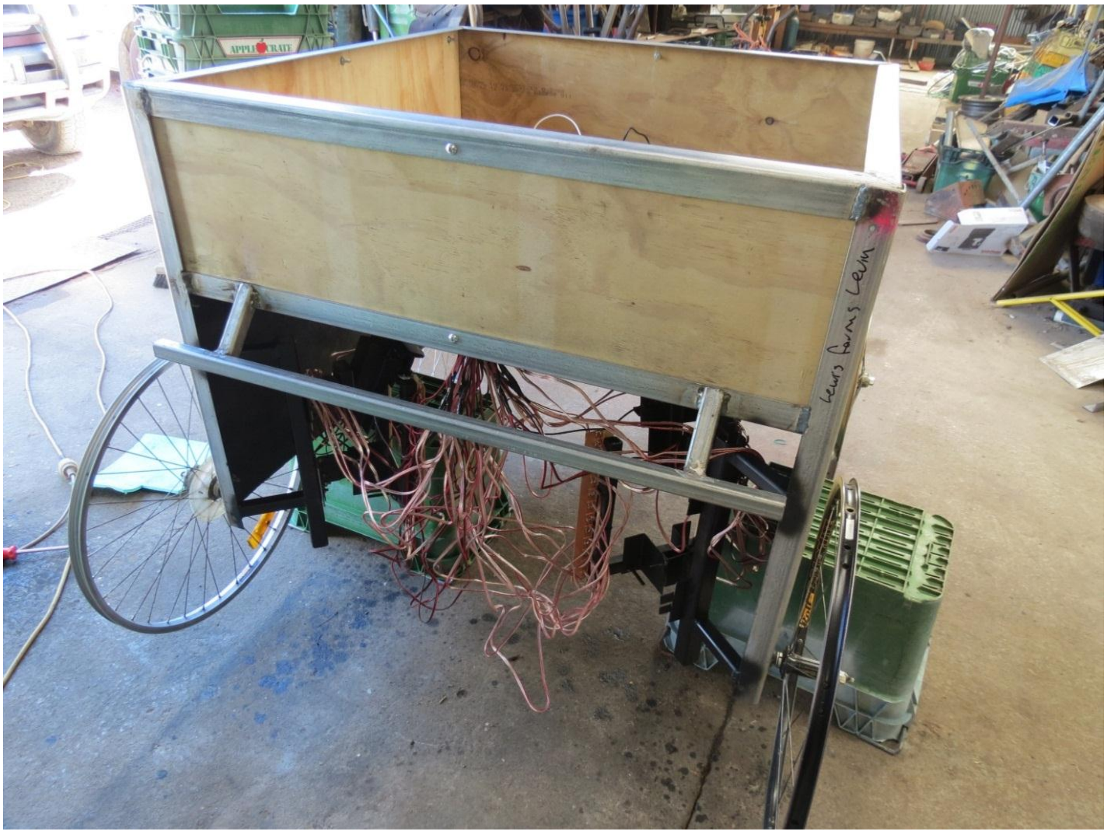

Figure 3.2. The constructed test rig with the camera and light mounts attached

Figure 3.3. The inside of the constructed test rig

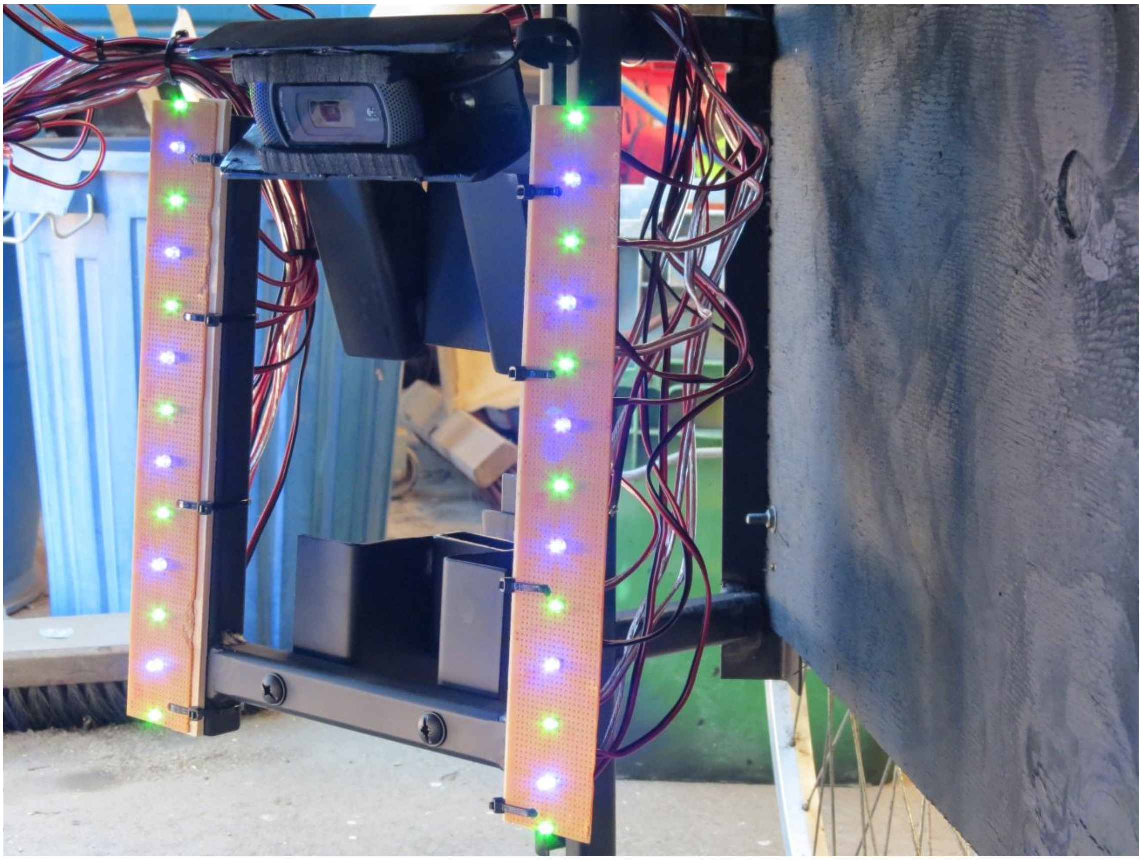

Figure 3.4. The camera and lighting mounts attached to the test rig through the extension

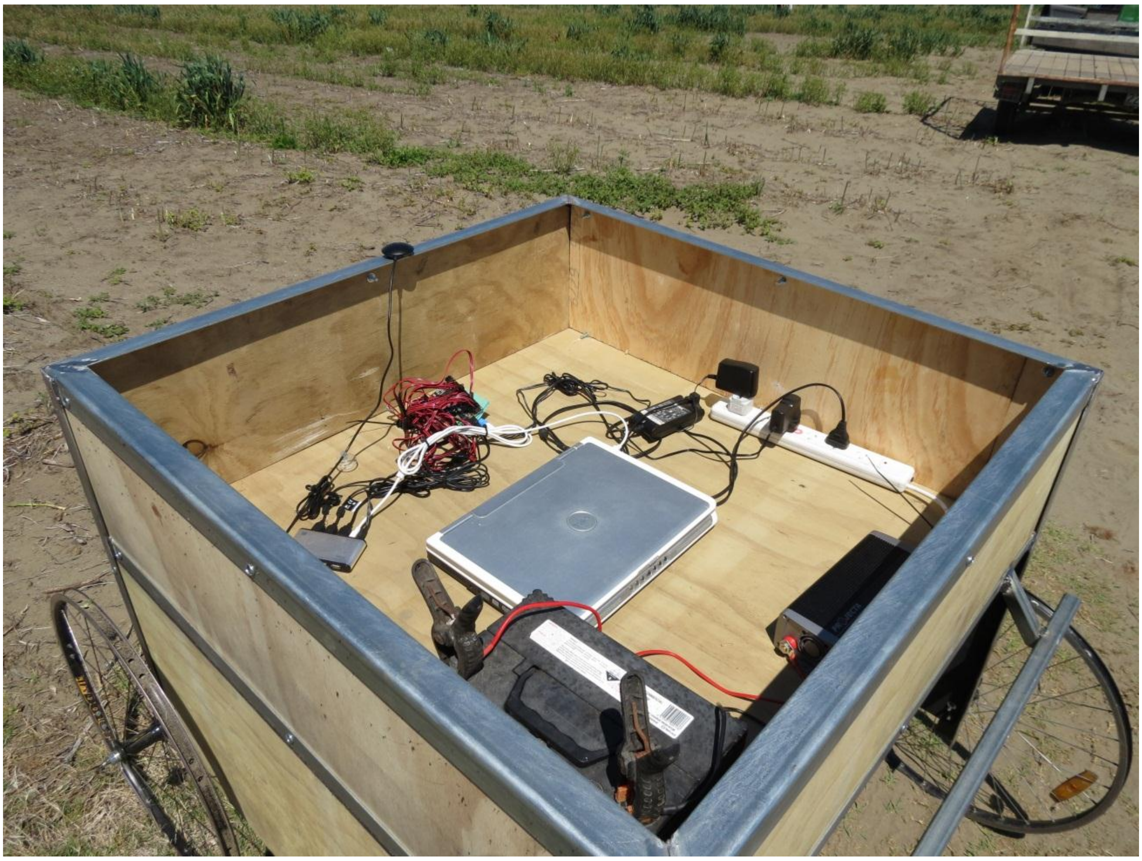

Figure 3.5. The storage area of the test rig

Figure 3.6. The test rig in an asparagus field without the curtains

4. Milestone Results

The test rig was pushed through an asparagus field, and the wheels proved suitable. The extra width made it easier to push while not walking on top of the asparagus rows.

The lighting system is too narrow and comes into contact with asparagus spears that deviate significantly from the centre of the rows. This project is assessing the feasibility of automated asparagus harvesting therefore the lighting system will not be moved unless the progress of task 1.1.15 system testing and improvements deems it necessary.

The storage box worked well, holding all of the required components while preventing sand from damaging them.

5. Milestone Budget

This milestone was met over budget. The materials cost more than expected, and the time required was slightly less than expected. This led to the overall budgeted cost of work performed (BCWP) being more than the budgeted cost of work scheduled (BCWS).

Hours		Materials		Budgeted Cost of Work	
Budgeted	Actual	Budgeted	Actual	Scheduled (BCWS)	Performed (BCWP)
39.5	39.1	$689.11	$741.65	$1,790.55	$1,831.93

Table 5.1) An actual and budgeted breakdown for the costs of this milestone

6. Milestone Conclusions

The designed and constructed test rig is capable of being pushed through asparagus paddocks, and the camera mounting system can be modified without requiring major modifications to the test rig.

7. Milestone Success

The milestone was met, and the client was very happy with the results.

Milestone 1.1.16 Report

1. Milestone Summary

WBS	Task Name	Scheduled Finish Date	Realisation Date	Realisation Summary
1.1.15	System Testing & Improvements	02/01/2013	02/01/2013	Completed on schedule
1.1.16	Obtain Approval of Performance	02/01/2013	02/01/2013	Completed on schedule

Table 1.1) A summary of the milestone including important dates

This milestone was met on schedule and on budget.

2. Milestone Aim

A mobile rig, camera system and data logging system that all work in conjunction with each other under typical asparagus field conditions to identify harvestable asparagus spears, calculate their coordinates, and store the location of them using a GPS shall be tested and perform to an acceptable level. This level shall be defined by the results of milestone 1.1.2. The asparagus season typically finishes immediately prior to New Year's Day, therefore the timely achievement of this milestone is very important.

Milestone 1.1.18 was also incorporated into this milestone at an earlier date in the project, which has the following aim:

Software that makes decisions on how to harvest asparagus spears in any typical orientation with a range of asparagus spears surrounding the target area, based on a given set of rules established by prior knowledge shall be developed. This software shall assume that the asparagus can be harvested by a mechanism approaching from any position and any angle surrounding the asparagus spear.

3. Milestone Process

This year the asparagus fields closed for harvesting earlier than expected, and the last field to close was in the furthest away asparagus block located 26km from the office. This meant that at the start of the testing task a large amount of testing was performed with the developed software so that the software was less likely to crash unexpectedly in the field. Also because the software would be running on a laptop not capable of modifying the software's source code capability needed to be built in so that sensor levels and light levels could be easily adjusted if required. This coincided with bad weather that prevented testing.

Asparagus at a typical harvestable height was found amongst the taller asparagus and harvested before being inserted into bare ground alongside the established asparagus rows, see figure 1. The harvester was pushed along and the sensors within the test-rig detected asparagus spears of a suitable height and calculated their location and size. The curtains on the test-rig pushed the spears over unless they were first placed inside the curtain due to them being harvested and placed shallowly in the ground. The sand was very shiny compared to the dirt used for initial software development so major modifications were made to the software. The asparagus detection process was altered significantly using the images obtained during the first test, before a second test was performed two days later. Only single spears were tested using this approach.

The second test returned much better results however further software modifications were required. 31 different asparagus spears were tested with the software, and the sizes and lengths were measured crudely using a ruler. The sizes calculated using the software were compared to the measured sizes, and different software configurations tested. The final asparagus spear detection process is shown in figure 2.

There was no way to determine if the software calculated the location of the asparagus spears accurately so the distance between asparagus spears was tested. Two asparagus spears were placed inside the test rig and photos taken. This was repeated three times with different asparagus spears each time, before the calculated values were compared to distances measured using a ruler.

The ability to calculate the angle of approach for a robotic arm is in the software, through knowing the location of multiple detected asparagus spears. The spears can be harvested from an angle at which no other spears are present between the robotic arm and the spear of interest.

Figure 1) Asparagus spears lined up for testing

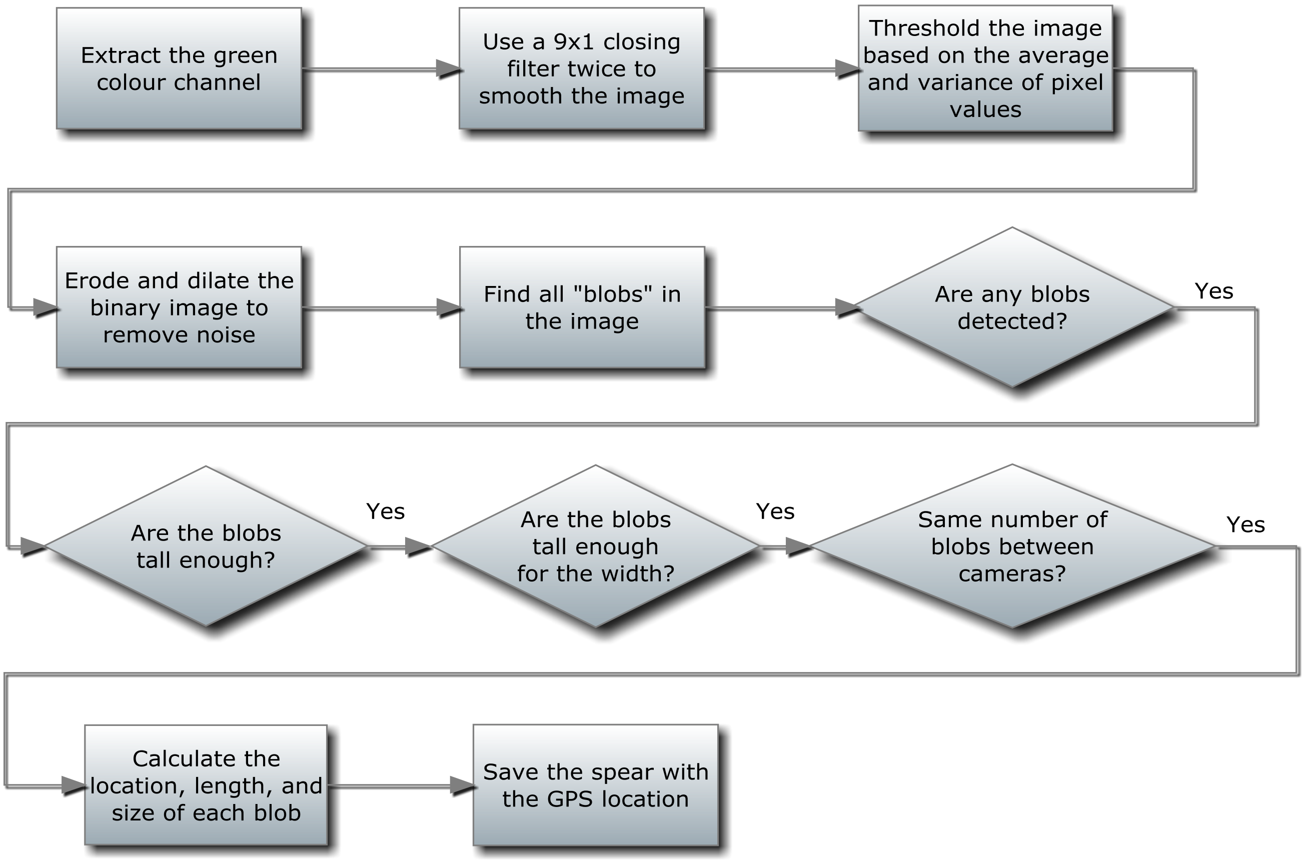

Figure 2) The asparagus detection software process

4. Milestone Results

The software was tested using 31 different asparagus spears, and the threshold limits[3] for converting the greyscale images to black and white was tested with three different values, a low, medium, and high level, see table 3. The length refers to the length of the asparagus spear, the major axis is the largest diameter of the asparagus spear and the minor axis is the diameter perpendicular to the major axis.

The higher thresholds were very successful in detecting asparagus spears, however as the threshold limit was increased the errors also increased, see figures 4-6. This is because the illumination of asparagus spears was not largely different from the illumination of the sand. This is likely due to the new wide-angle LEDs that were used during testing opposed to the narrow-angle LEDs that were used during initial software development. If more time was available this is likely to have been fixed by arranging narrow-angle LEDs in several columns that are each set at a different angle, therefore illuminating any asparagus spears while not illuminating the sand as much.

[3] When an image is thresholded the brightness of the greyscale pixels are analysed, and if they are on one side of a defined limit they are set to black while on the other side of the limit they are set to white resulting in a binary image.

The errors in length calculations as well as size calculations are likely to reduce with the proposed lighting and appropriate measuring equipment. The errors will likely decrease further with improved cameras operating at higher resolutions.

The most important function of the asparagus detection software is to calculate the location of asparagus spears. There is no method to determine this accuracy without a robotic arm or other precision tool, however the separation between asparagus spears can give an indication of this accuracy. Three pairs of asparagus spears were tested and the largest error was slightly under 6mm, see figure 7. This is promising and demonstrates there is a high chance of the asparagus location detection being accurate. This accuracy is also likely to improve with higher resolution images and improved cameras.

The change in errors for the asparagus separation tests between the different threshold limits was relatively small. It should be noted that with the high threshold only two images were successful in their detection.

There is a chance that the software would have performed differently in the actual asparagus rows due to foreign matter and different conditions. This may have provided more disturbances for the software, or less through shielding the "shiny" sand. Unfortunately there was no way tests could be performed in this environment.

Because only two cameras were used the software has a inaccurate assumption when calculating the location of more than one asparagus spear in an image. The left asparagus spear in one image is assumed to be the left asparagus spear in the other image, which is not true for every case. With additional cameras this can be solved, however it was not known how to do this with only two cameras. If the spears are behind each other it is also not possible to identify each using only two cameras.

	Low Thresh	**Mid Thresh**	**High Thresh**
Overall Asparagus Detection Success	74.2%	80.6%	96.8%
Individual Asparagus Image Success	80.6%	91.7%	98.4%
Average Length Error (mm)	-8.5	-15.4	-18.4
Length Standard Deviation (mm)	13.2	14.5	13.3
Major Axis Error (mm)	-3.2	-3.8	-0.2
Major Axis Standard Deviation (mm)	4.0	3.6	22.2
Minor Axis Error (mm)	-4.2	-5.3	-5.8
Minor Axis Standard Deviation (mm)	1.9	1.8	1.7

Table 3) The detection and error results from the software testing

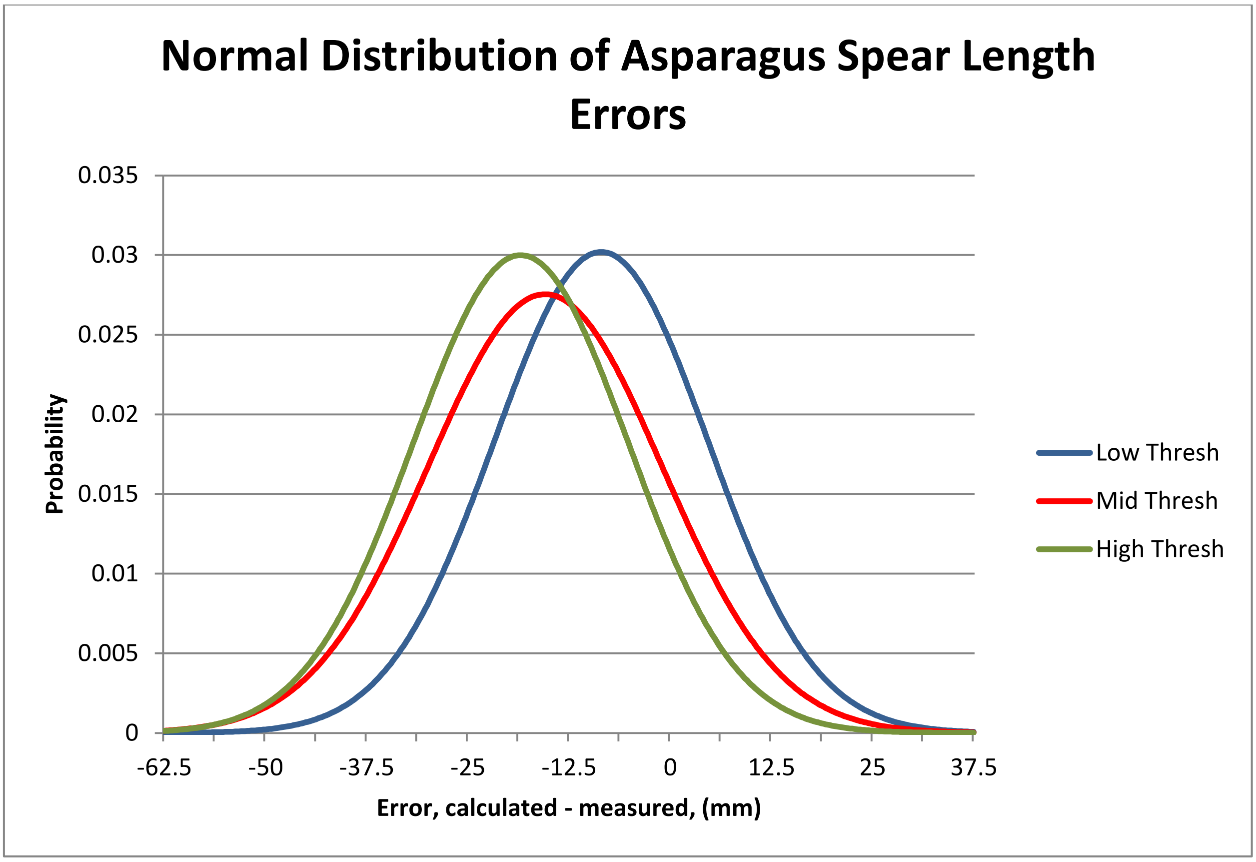

Figure 4) The normally distributed asparagus spear length errors from testing

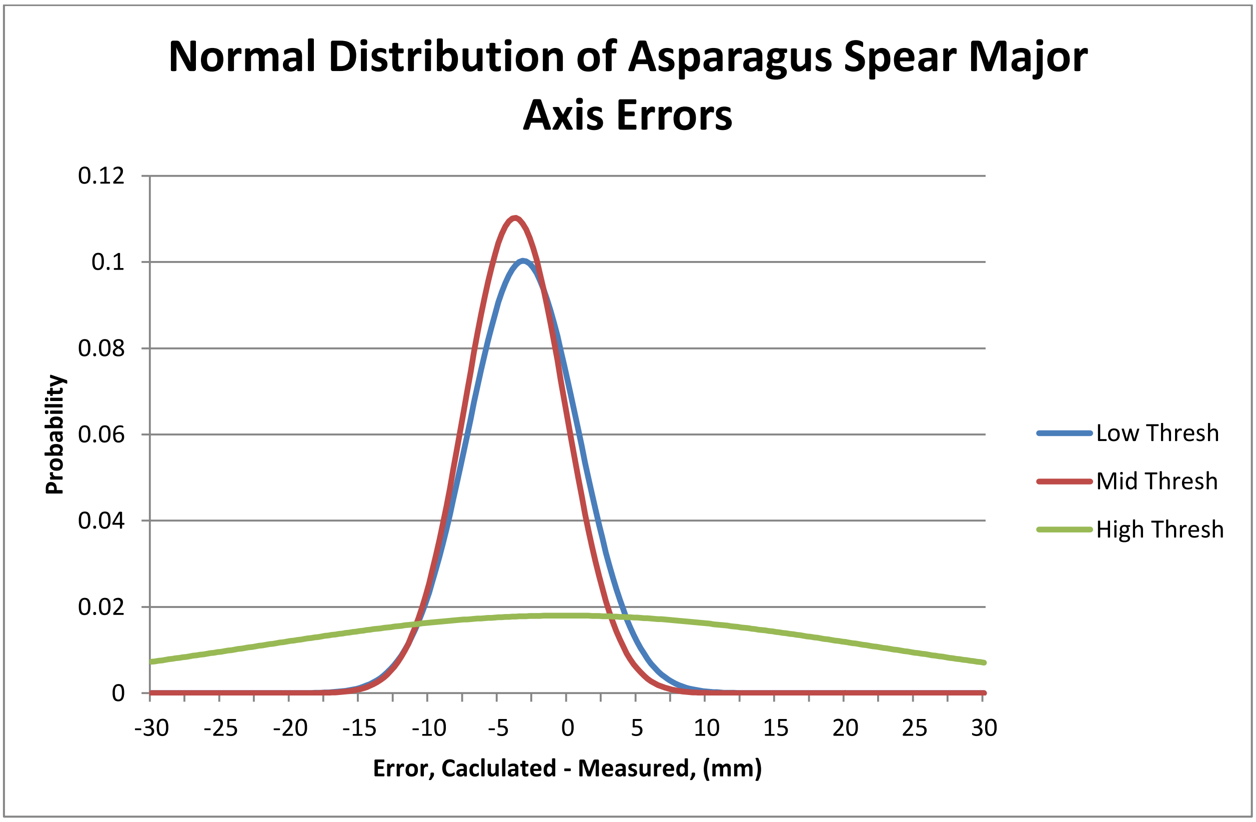

Figure 5) The normally distributed asparagus spear major axis errors from testing

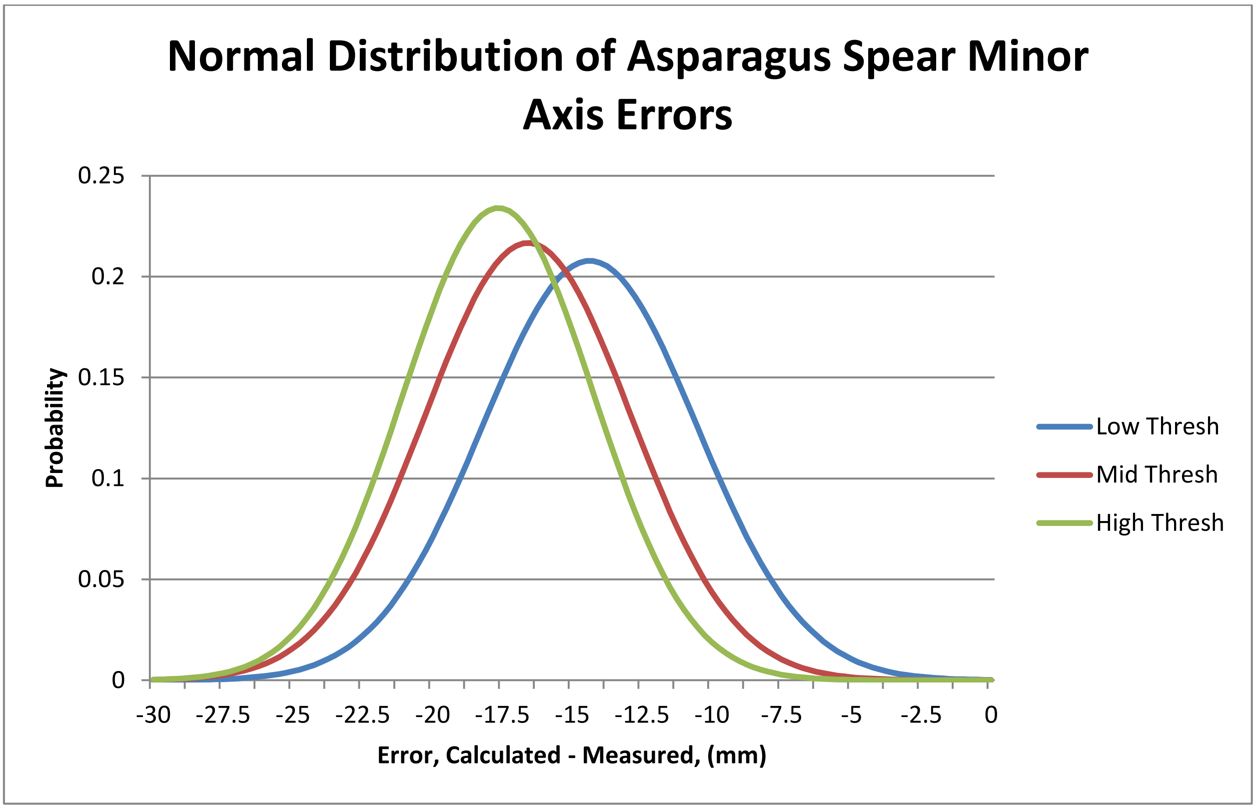

Figure 6) The normally distributed asparagus spear minor axis errors from testing

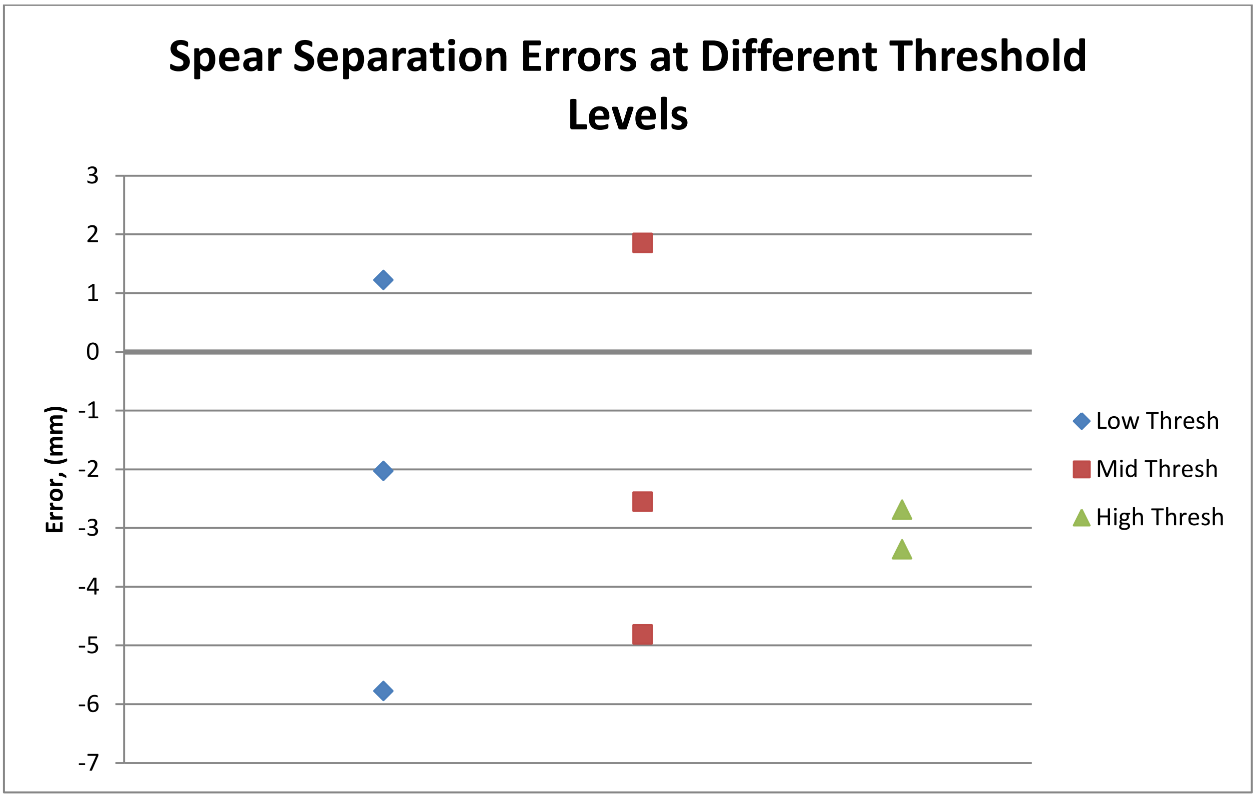

Figure 7) The error in the distance calculations between asparagus spears

5. Milestone Budget

Hours		Materials		Budgeted Cost of Work	
Budgeted	Actual	Budgeted	Actual	Scheduled (BCWS)	Performed (BCWP)
78	78.1	$0.00	$0.00	$2,175.00	$2,177.79

Table 8) An actual and budgeted breakdown for the costs of this milestone

The project was met on budget.

6. Milestone Tracking

Because of the Christmas and New Year's period this task was tracked by the day to ensure it was going to be completed on time. The project fell behind schedule however the time was quickly recovered, see figure 9.

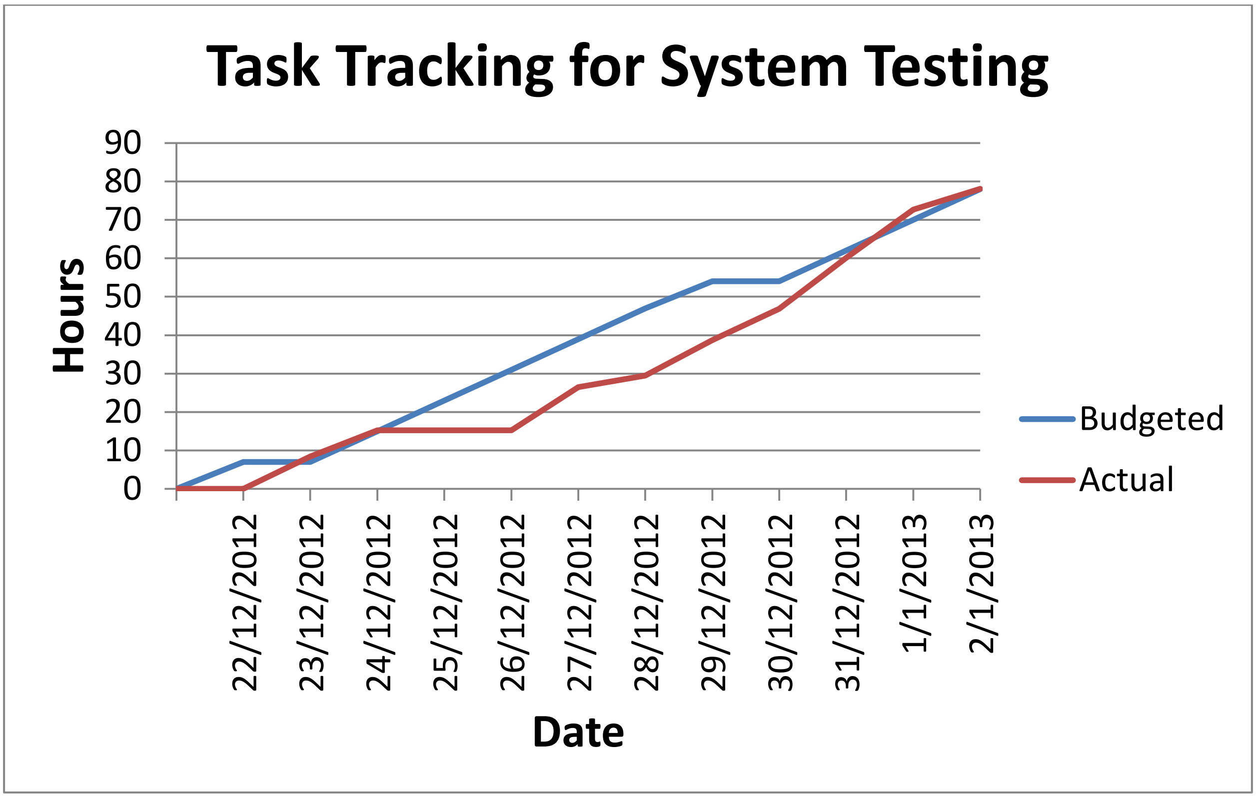

Figure 9) The tracking of the task over its duration

7. Milestone Conclusions

The test rig performed all of the required tasks well. Asparagus was detected, and it was saved both in a file for later use and in a Google Earth file using the correct GPS location to an expected accuracy. Using the data retrieved within the software it is also possible to calculate the angle of approach for a robotic arm to harvest asparagus.

8. Milestone Success

The milestone was met, and the client was happy with the results.

Milestone 1.2.4 Report

1. Milestone Summary

WBS	Task Name	Scheduled Finish Date	Realisation Date	Realisation Summary
1.2.1	Cost Saving Analysis	16/12/2012	14/12/2012	Completed ahead of schedule
1.2.2	Alternate Revenue Stream Analysis	19/12/2012	19/12/2012	Completed on schedule
1.2.3	Business Plan Development	21/12/2012	28/12/2012	Completed behind schedule

Table 1.1) A summary of the milestone including important dates

2. Milestone Aim

A detailed financial analysis incorporating both direct and indirect costs using data from the 2011 and 2012 asparagus seasons shall be performed. This will also include projections based on the estimated cost for the invention in terms of capital and maintenance. Another deliverable from this milestone includes a portfolio of potential revenue streams that can be generated by the invention including at a minimum: revenue generated from selling automated asparagus harvesters, revenue generated from employing staff to harvest for overseas growers during the NZ off-season, how the market will react to the availability of automated asparagus harvesters, and if the intellectual property (IP) can be leased out for other technologies.

3. Milestone Process

3.1. Cost Saving Analysis

The cost saving analysis began by obtaining all of the data relating to past harvesting and processing costs from the client. This data was analysed to determine exactly what the current harvesting costs are, and convert these into forms that could be compared to automated harvesting costs such as per hectare, and per year.

To calculate the estimated automated harvesting costs other information was required from the client relating to the asparagus paddocks such as plant density, and the amount of land Lewis Farms plans to have planted in asparagus in future years. Some numbers used in the calculations were estimates based on engineering knowledge and similar devices, so there is room for improvement as more information becomes available.

A performance check was used to confirm that the predictions were not unrealistic, which determined that one asparagus spear would be harvested every three seconds for each row of asparagus and confirmed the predictions realistic.

3.2. Alternate Revenue Stream Analysis

At the start of this task a brainstorming session was performed to determine what forms of revenue can be generated. This resulted in the following areas requiring research:

- Harvesting labour cost saving
- Selling automated harvesters as a product
    - Having a business unit that services sold automated harvesters
- Leasing generated intellectual property to other automated systems
- Harvesting asparagus for overseas asparagus growers during the NZ off-season

Using the cost saving analysis from task 1.2.1 the amount of money to be saved every year was calculated as this is the primary revenue stream from automated asparagus harvesters. This did not require much work as the majority was completed in task 1.2.1.

The price at which automated asparagus harvesters could be sold was made using several assumptions:

- What is the minimum amount of asparagus a grower would have who would want an automated asparagus harvester?
- What payback period would growers want?

Using the above information a predicted number of sold machines per year was made and the impact on Lewis Farms' business was analysed.

The option of leasing IP to similar systems was first analysed by determining how many countries the IP protection would need to cover. Asparagus is grown in a wide range of countries in much larger quantities than NZ so the cost of obtaining IP protection ruled this option out relatively early.

The amount of green asparagus grown in each country was the starting point to determining if asparagus can be harvested overseas. The minimum wage rates relative to the NZ minimum wage rates were compared to find countries that were likely to pay more for the asparagus to be harvested. An area was identified as viable so research was performed to determine if there was a need for automated harvesting in this area. Through several online newspaper articles it was confirmed that there was a large shortage of asparagus harvesters in that area. These enabled further predictions to be made ascertaining how much profit can be made from harvesting asparagus in that particular area.

Other revenue generation factors that involved changes to current asparagus growing practices started being explored as planned however the client preferred that these were ignored since the current focus is on lowering harvesting costs for the current growing practices.

3.3. Business Plan Development

Using the information obtained from tasks 1.2.1 and 1.2.2 two directions were explored for the commercial development of an automated asparagus harvester. The net present value and internal return rate for both of these options were calculated to find the more suitable option. A business plan was developed around these projections, taking into consideration the nature of Lewis Farms' current business and the impact a large investment may have. Because a commercially viable automated harvester is at least three years off the business plan had sections changed and added to make it more helpful to Lewis Farms as a guiding document. The focus of this guiding document was then to provide information to Lewis Farms about how a new company could operate, what financial predictions had been made, what decisions need to be made, and what key areas need to be monitored. A draft copy was submitted to the client, and minor changes were made before being approved as acceptable quality.

4. Milestone Results

A revenue generation document was created that outlines the results from both the cost saving analysis and revenue generation options, see attached file.

A guiding document was created that contains information expected in a business plan as well as other information that will be helpful to Lewis Farms in their decision whether to continue this project through to a commercial stage or not, see attached file.

5. Milestone Budget

This milestone was met under budget. There were no material costs for any of the tasks as expected.

- Task 1.2.1 was met a long way under budget due to the client reducing the scope significantly.
- Task 1.2.2 was very slightly over budget.
- Task 1.2.3 was over budget due to the client requesting changes to be made. During these changes the weather was impacting on the next scheduled task, so additional time was available put into task 1.2.3 rather than wasting the time entirely.

Task	Hours		Materials		Budgeted Cost of Work	
	Budgeted	Actual	Budgeted	Actual	Scheduled (BCWS)	Performed (BCWP)
1.2.1	36.5	19.5	$0.00	$0.00	$1,017.79	$543.75
1.2.2	20	20.8	$0.00	$0.00	$557.69	$580.00
1.2.3	20	27.9	$0.00	$0.00	$557.69	$777.98
TOTAL	76.5	68.2	$0.00	$0.00	$2,133.17	$1,901.73

Table 5.1) An actual and budgeted breakdown for the costs of this milestone

6. Milestone Conclusions

The forecast cost savings and possible revenue streams have been analysed and put into a business guiding document. The analyses performed will allow decisions to be made by the client with regards to what finances can be expected, and other factors that need to be considered and monitored if an automated asparagus harvester is going to be developed in the near future.

7. Milestone Success

The milestone was met, and the client was happy with the results.

D. Guiding Document

Robotic Harvesting Ltd.

Guiding Document – Jan 2013

This document will serve as a guide to how the new business "Robotic Harvesting Ltd." should develop and operate automated asparagus harvesters, as well as providing information on other key areas that need to be monitored.

Robotic Harvesting Limited Business Plan – Jan 2013
2/1/2013

Executive Summary

Asparagus growers have reached a point where automated asparagus harvesting must be explored. This is due to high labor costs preventing the asparagus growing business from expanding.

The directors of Lewis Farms should create a business known as Robotic Harvesting Limited (RHL) that will contract out the development of an automated asparagus harvester and harvest asparagus for New Zealand and California asparagus growers. This is expected to have an internal return rate (IRR) of 33% and a net present value (NPV) of over NZ$1.6 million 10 years after development first begins.

Lewis Farms and one other investor are each required to contribute an accumulated sum of money according to the following timeline:

Required Funds per Investor										
Year	1	2	3	4	5	6	7	8	9	10
Money ($000)	$133	$273	$422	$449	$399	$190	-	-	-	-

There is an opportunity for Lewis Farms to guarantee their crop can be harvested while with another investor making a profit through harvesting other farmers' asparagus for an accumulated sum that adds to:

Accumulated Cost Savings / Profit										
Year	1	2	3	4	5	6	7	8	9	10
Money ($000)	-	-	-	-	-	-	$357	$1,388	$2,716	$4,340

Californian asparagus growers are experiencing labor shortages to the degree that at least one farmer is not harvesting 40 hectares of asparagus purely due to a labor shortage, therefore this market can be targeted and produce a profit of $83,000 per automated asparagus harvester per season. The NZ domestic harvesting profit is slightly less due to the shorter asparagus season, but still a significant $65,000 per harvester per season.

In exchange for a 50% monetary investment, one other investor will receive a 33% share in the formed company, which will cover ownership of the developed intellectual property and rights to dividends. It is also assumed that the Ministry of Science and Innovation (MSI) will fund half of the expected development costs.

The automated asparagus harvester concept has been proven technically feasible, and a developer is required. Industrial Research Limited (IRL) has expressed interest in developing a harvester, however further discussions are required.

Contents

1. Background Information

Asparagus has traditionally been harvested by hand, however fewer New Zealanders are willing to perform this task. A feasibility study has been conducted that concludes that it is both technically possible, and financially beneficial to harvest this asparagus using automated machines.

This business plan outlines how a business start-up should pursue the development of a commercial automated asparagus harvester, and how best to maximise the economic value of doing this.

1.1. Mission Statement

Robotic Harvesting Limited (RHL) aims to harvest asparagus for New Zealand and International asparagus growers through automated solutions to allow asparagus growers to expand.

1.2. Business Goals and Objectives

Goals:

- To have a commercial automated asparagus harvester operating successfully in asparagus paddocks by the conclusion of the year 2016.
- To harvest asparagus at a cost of under $0.50/kg excluding interest on finance by the conclusion of the year 2016.
- To have a payback period of no more than 6 years after development first begins.

Objectives:

- To find a suitable engineering firm to continue the development of an automated asparagus harvester.
- To develop an automated asparagus harvester that requires minimal maintenance and minimal start-up procedures.
- To develop an automated asparagus harvester than is accurate on a wide-range of asparagus farms so it can be used in a range of conditions.
- To find investors so the cost of development is minimised.

1.3. Description of the Business

- RHL is in the business of harvesting asparagus.
- RHL is not run by any asparagus growers, instead they are independent contractors that are hired by asparagus growers.
- A very large market exists because New Zealand is experiencing labour shortages with regards to harvesting asparagus, and New Zealand only contributes to 1.1% of the world's asparagus land[1].
- RHL will operate as a limited liability business.

[1] http://www.calif-asparagus-seed.com/img/2009_world_asparagus_production.pdf

- The peopled involved in the operations will be:
    - A governance team overseeing the direction of the business.
    - An engineer who will manage the daily asparagus harvesting and solve any problems that arise.
    - Two teams of people to operate the machines in the two asparagus harvesting shifts.
- The business has not been created yet, however a technical feasibility and financial analysis has shown there is a high chance of this venture proving worthwhile.
- The business is projected to grow to a value of $1.4 million in 5 years, and $9.5 million in 10 years.

2. Market Analysis

2.1. Current Market Environment

The market for automated asparagus harvesters is currently very large, and includes several countries. New Zealand has already expressed interest with one asparagus grower very interested in automated asparagus harvesting. Asparagus growers around the world including California are experiencing labour shortages, which is increasing the demand for automated solutions[2]. **California is a market that can be targeted** because:

- The California asparagus season does not have any overlap with the New Zealand asparagus season, so growers don't need to switch between manual and automated harvesting.
- California grows a large amount of green asparagus, so finding growers to harvest for should be relatively easy.
- The wage rate in California is relatively similar to that in New Zealand.

After the Californian market has been explored there are other countries with adequate amounts of green asparagus, and the United Kingdom is currently implementing large expansions on asparagus farms, see table 1 for a full breakdown by country.

[2] http://www.agalert.com/story/?id=4192

Country	Gross Annual Wage (Intl. Dollars)	Relative Hourly Wage in NZ$	Asparagus Area (ha)	Asparagus Yield (kg/ha)	Green Asparagus Percentage	Total Green Asparagus Production (tonne)	Overlap with NZ Season (Y/N)
China	-	-	57,000	12,000	50%	342,000	Y
Germany	-	-	22,000	6,200	4%	5,456	N
Italy	-	-	6,000	6,775	80%	32,520	N
Australia	33,033	$27.09	1,604	6,100	95%	9,295	Y
Netherlands	23,029	$18.89	2,450	6,120	2%	300	N
United Kingdom	22,597	$18.53	1,478	3,200	100%	4,730	N
France	17,108	$14.03	7,000	5,000	15%	5,250	N
Canada	16,710	$13.70	1,200	4,000	100%	4,800	N
New Zealand	16,462	$13.50	630	4,500	100%	2,835	-
USA (California)	15,080	$12.37	5,400	3,250	100%	17,550	N
Taiwan	12,175	$9.98	1,100	7,000	100%	7,700	Y
Spain	11,426	$9.37	11,000	6,500	75%	53,625	N
Japan	11,254	$9.23	65,000	5,000	99%	321,750	Y
Greece	8,204	$6.73	4,280	3,700	1%	158	N
Poland	7,732	$6.34	1,500	3,000	5%	225	N
Argentina	7,462	$6.12	1,200	3,400	70%	2,856	Y
Iran	6,618	$5.43	1,000	3,000	UNKNOWN	3,000	N
Chile	5,484	$4.50	2,700	5,000	100%	13,500	Y
Peru	5,342	$4.38	26,800	9,500	83%	211,318	Y
Thailand	4,318	$3.54	2,840	11,500	98%	32,007	Y
South Africa	2,471	$2.03	1,080	3,580	71%	2,745	Y
Mexico	1,753	$1.44	18,300	4,500	100%	82,350	Y

Table 1) Countries with over 1,000 hectares of asparagus, and New Zealand including important information

2.2. Current and Future Competitors

There are currently two automated asparagus harvesters being commercially used for green asparagus; the Geiger Lund Selective Asparagus Harvester Model SP-2010, and the HAWS Mechanical Asparagus Harvester.

The Geiger Lund Selective Asparagus Harvester Model SP-2010 has an estimated cost of $150,000, and the HAWS system does not indicate a cost.

Neither of the above systems harvest a high percentage of asparagus spears without permanently damaging neighbouring asparagus spears, therefore they are not suitable for quality-focused asparagus farmers.

A large amount of research is being conducted around selective asparagus harvesting, however no reports indicate that there is going to be a viable solution in the near future.

There are automated asparagus harvesters that are effective for white and purple asparagus, however due to the different growing conditions between white, purple, and green asparagus it is unlikely that these systems will be able to be applied to green asparagus plantations.

2.3. Market Influences

The New Zealand Government wants the primary industries to expand, so more money enters the country through exports. For this reason **the Ministry of Science and Innovation is investing large amounts of money into research and development projects** centred around the primary industries.

If the labour shortage disappears it is likely that overseas governments will introduce barriers to prevent automated asparagus harvesters from being used where they are not required. These barriers will reduce the economic viability of harvesting asparagus overseas, and the overall viability of developing automated asparagus harvesters.

There are often negative opinions about automation with regards to taking jobs away from people. This may have a negative impact on the business, and asparagus growers may not want to be associated with this negative attention.

3. Product Description

3.1.Benefit to Customers

The **main benefit to customers is that all of their asparagus will be harvested** and this will occur **sooner** than usual. This means that paddocks can be harvested daily to improve the quality, and growers have less problems finding enough staff to harvest all of the asparagus.

There are other benefits that will arise later in the development of automated asparagus harvesters:

- Increased crop density since people will not need to walk up every asparagus row.
- Improved genetics through identifying high-producing asparagus plants and using these in a plant breeding programme.
- Harvesting asparagus immediately before a forecast frost to minimise lost crop and reduce the time before the asparagus recovers and can be harvested again.
- Reduced factory processing costs through grading thin asparagus spears during harvesting and sending these straight to the cannery.
- Improved quality through harvesting a portion of the asparagus at night so it is exposed to less heat after harvesting.
- Improved feedback on plant response to fertiliser or spray after application.
- Ability to harvest asparagus in any weather.
- Improved forecasting of supply levels.

3.2. Value-Adding Functionality

The functionality that allows all asparagus paddocks to be harvested sooner is the ability for the automated asparagus harvester to **harvest asparagus from more than one row at a time while travelling faster than people** walk while harvesting asparagus.

The increased crop density arises from the machine being able to span several rows while harvesting, compared to humans needing to walk alongside every row. Therefore new asparagus paddocks can be planted with more rows of asparagus in a given area.

The improved genetics will arise from the automated asparagus harvester having a very-high accuracy GPS system that combined with the precision camera system will identify the size of an asparagus spear and know what plant it is from the GPS location. Over the duration of the asparagus season each days information will be aggregated so at the end of the asparagus season the top producing plants can be identified before being cloned and placed into a plant breeding programme.

The precision camera system will identify the size of asparagus spears, and if they are below a defined threshold then they can automatically be stored in a different crate. A sorting mechanism that stacks asparagus spears into crates will have the functionality to divert small spears when necessary.

The camera system requires a uniform lighting environment which is why the harvester is fully enclosed and the only lighting for the camera system is provided by a number of controlled Light

Emitting Diodes (LED's). Because of this the harvester is able to work during the night and the day without experiencing a performance change.

Because of the earlier mentioned precision camera system and very-high accuracy GPS system the size of asparagus spears between days can be compared. This allows data to be analysed before and after fertiliser or chemicals are applied to asparagus paddocks, so the plant responses to these can be analysed.

The improved forecasting of supply levels is through identifying trends and patterns in asparagus growth. This will have flow on effects for growers such as maintaining customer relationships through improved communications about supply, and telling the processors how much crop they will be receiving.

3.3. Enabling Technology

All of the technology required to develop an automated asparagus harvester has existed for many years, however the cost of this technology relative to manual harvesting has been the restricting factor. The **cost of technology has been steadily decreasing** alongside wage rates increasing and the tipping point for a robotic automated asparagus harvester has recently been reached.

The major components required to develop the envisaged automated asparagus harvester are:

- High-resolution cameras.
- Controllable lighting system.
- Six degree of freedom robotic arm.
- High speed computer.
- Conveyer and sorting system.
- Mobile platform with steering system.
- Real Time Kinematic (RTK) GPS system.
- Infrared sensors.
- Power source to run the electronics and platform.

3.4. Evidence of Customer Need

This project was started because **Geoff Lewis from Lewis Farms is experiencing labour shortages**, and has been forced to use Samoan workers through the Recognised Seasonal Employer (RSE) scheme. This is incurring large costs and this is unlikely to change in the foreseeable future.

There is evidence all over the news of asparagus growers experiencing labour shortages. One asparagus farmer in Washington recently abandoned 40 hectares of asparagus because he did not have enough labour to harvest all of his asparagus[3]. A simple Google search for "asparagus labour shortage" returns a large number of recent articles about asparagus farmers not having enough staff.

[3] http://www.takepart.com/article/2012/05/15/farm-labor-shortages

The importance of different design decisions have been determined through a survey of 6 different asparagus growers, see figure 2.

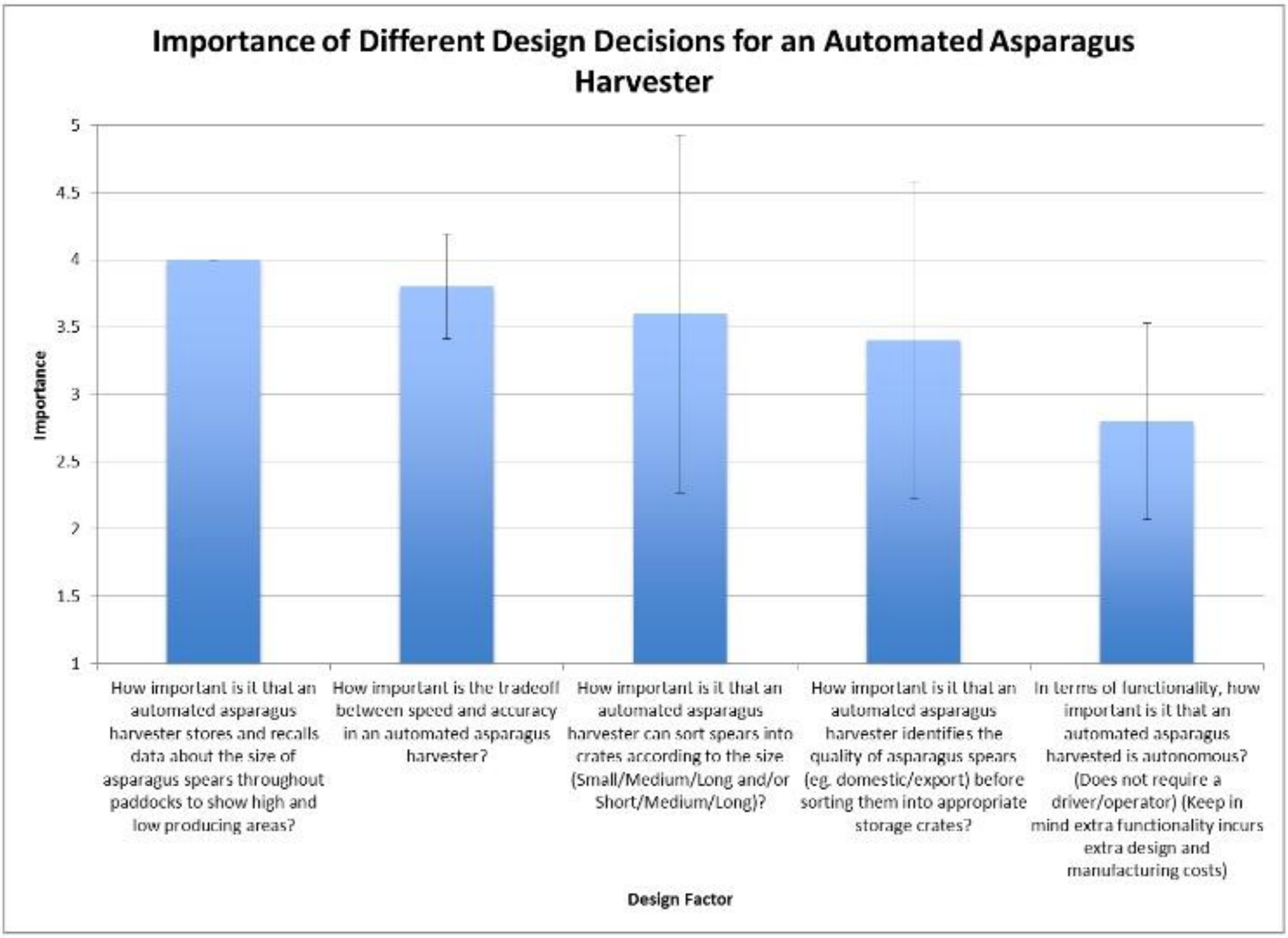

Figure 2) Survey results from 6 different asparagus growers

4. Development & Production

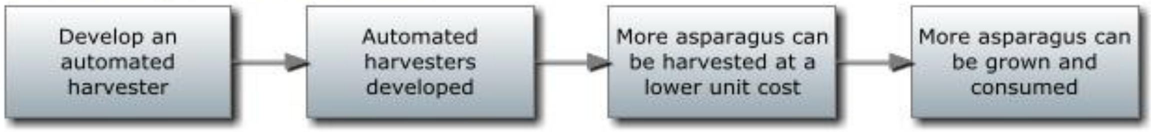

Figure 3) A flowchart showing the required steps for automated asparagus harvesters

A low-cost feasibility study has been completed that concludes it is technically possible to robotically harvest green asparagus. The next step is to start developing an automated asparagus harvester that performs all of the required tasks from locating asparagus spears to harvesting and packing these spears. Technology developments such as the proposed one typically follow an s-curve, see figure 4. The development stage will focus on the highlighted area, and after development the factors further up the curve will be targeted.

It is expected that there will be five design stages in order to reach a commercially suitable automated asparagus harvester. This development needs to be aligned with the NZ asparagus season so that testing can be performed in real asparagus paddocks during the asparagus season.

Another investor is required to lower the amount of money needed to develop an automated asparagus harvester. Because this investor has not come up with the idea and started the movement towards developing an automated asparagus harvester it is expected that for their 50% monetary investment they will only receive a 33% ownership of the created company. This ownership will include ownership of the intellectual property developed as well as rights to dividends.

The testing during the development of an automated asparagus harvester should be as close as possible to where the development is taking place. This will reduce time and costs incurred during testing. If it is not possible to have a test area near the development location then the test area should be as close to a major airport as possible so that the harvester to be tested can be easily transported and tested within a short space of time.

One option for development is a young technology business. This could lead to cheaper development costs than other developers, however due to inexperience the performance of the final product could be less as a result. There is also a risk that they will not have the skills or experience required to complete the job.

Another option is to use a university to develop the harvester. Universities will have the skills and facilities to develop a harvester. One risk is the attention that this may receive if it was being developed at a university, and this may lead to competitors developing solutions sooner.

A Crown Research Institute (CRI) such as Industrial Research Limited (IRL) could be used for the development. IRL has completed other technical projects so they know are familiar with the development process and have the required skills. They will also be useful with regards to securing funding from the Ministry of Science and Innovation (MSI).

After an automated harvester has been developed a reliable manufacturer will need to be sourced. The relationship with this manufacturer should be carefully developed as it is likely that collaboration will be required when making modifications in future years. Also the results from one manufacturer rather than changing between manufacturers are likely to be better, therefore the manufacturer's history should also be observed. This manufacturer could be the other required investor, or an external company.

Depending on who is chosen to develop an automated asparagus harvester, the risks will need to be observed and appropriate contingency plans put in place.

Figure 4) The S-curve description of new products and innovations

4.1. Porter's Five Forces

Figure 4 explains the competitiveness, intensity and attractiveness of the asparagus growing market once automated harvesting has been developed from a growers point of view.

Competitive Advantage:

If a grower is first to adopt automated harvesting they will have a **significant competitive advantage**. This is **not sustainable** as competitors will be forced to also adopt automated harvesting to remain competitive.

Competitor Reaction:

Competing growers will be forced to adopt automated harvesting. Their higher harvesting costs will not allow them to sell their produce as cheaply. **Competitors will have little choice but to adopt automated harvesting** that doesn't infringe on any patents or other established intellectual property. Smaller growers will be absorbed into the automated businesses or will leave the market.

Target Markets:

The target markets for growers **will not change.** There will be an increased supply to the current markets, and if the current markets become saturated then other markets can then be explored. As the world population increases and also becomes more affluent, these markets will emerge.

Market Accessibility:

Markets to the horticulture industry are largely supply driven, and with the expected increase in NZ growers' production **current markets will remain accessible**[9], see figures A.1 and A.2. There is a risk of decreased prices through increased supply, however the increased profit margin through automated harvesting will help to offset this. As the global demand increases it is likely the price will also increase.

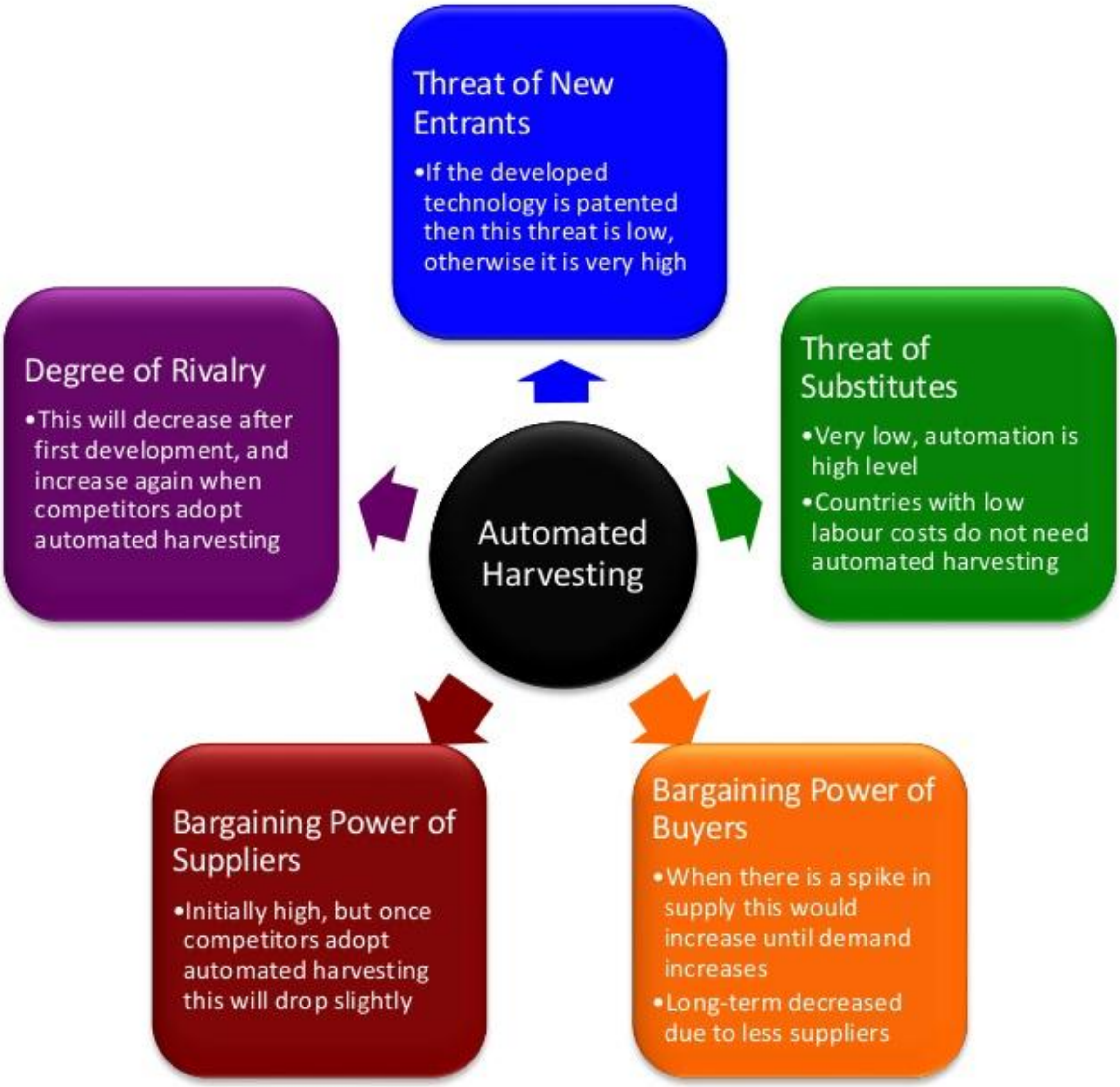

Figure 5) Porter's Five Forces Analysis on the creation of automated harvesting

4.2.Project Risks

There are several project risks associated with the different components of the project, see figure 6.

Probability of Technical Success:

The current probability of technical success is 70%. This figure is based on the outcome of similar projects, and that the results to date in the low-cost feasibility study are promising. Robotic kiwifruit harvesters are getting closer to reality[4], and this is likely to be a more complex task than robotic asparagus harvesting due to kiwifruit being grown in above-ground vines at various heights opposed to asparagus growing from the ground which is a fixed height.

Probability of Regulatory Success:

The current probability of regulatory success is 95%. This is because there are currently no regulations against robotic asparagus harvesting, and because the asparagus industry is experiencing a large labour shortage it is unlikely any barriers will be raised to halt robotic asparagus harvesting.

Probability of Obtaining another Investor:

The current probability of obtaining another investor is 50%. The project has a high risk of failure due to the highly technical nature of it, which will warrant investors wanting a large return for their investment. The financial returns explained in section 6 are relatively low for the inherent risk. Commercialisation companies such as powerHouse in Christchurch and The Bio Commerce Centre in Palmerston North are able to assist in obtaining investment if required.

Probability of Commercial Success:

The current probability of commercial success is 50%. This is because of the combination of other risks explained above, as well as the large amount of time and effort that will need to be placed into RHL. Lewis Farms is already a mature business returning steady profits therefore the drive to push RHL to succeed may not be as present as if Lewis Farms was a relatively new business. If Lewis Farms does have the drive to make RHL succeed then there is a large chance that it will as long as the other risks are managed.

Risk Summary:

The probability of commercial success and probability of obtaining another investor are currently too low as shown in figure 6. The probabilities of these factors succeeding need to be increased to at least 70% before the project commences and if any other risks arise these need to be inserted into the risk radar plot and improved where possible.

[4] http://nz.lifestyle.yahoo.com/autos/features/article/-/15138923/kiwis-leading-the-way-in-orchard-robotics/

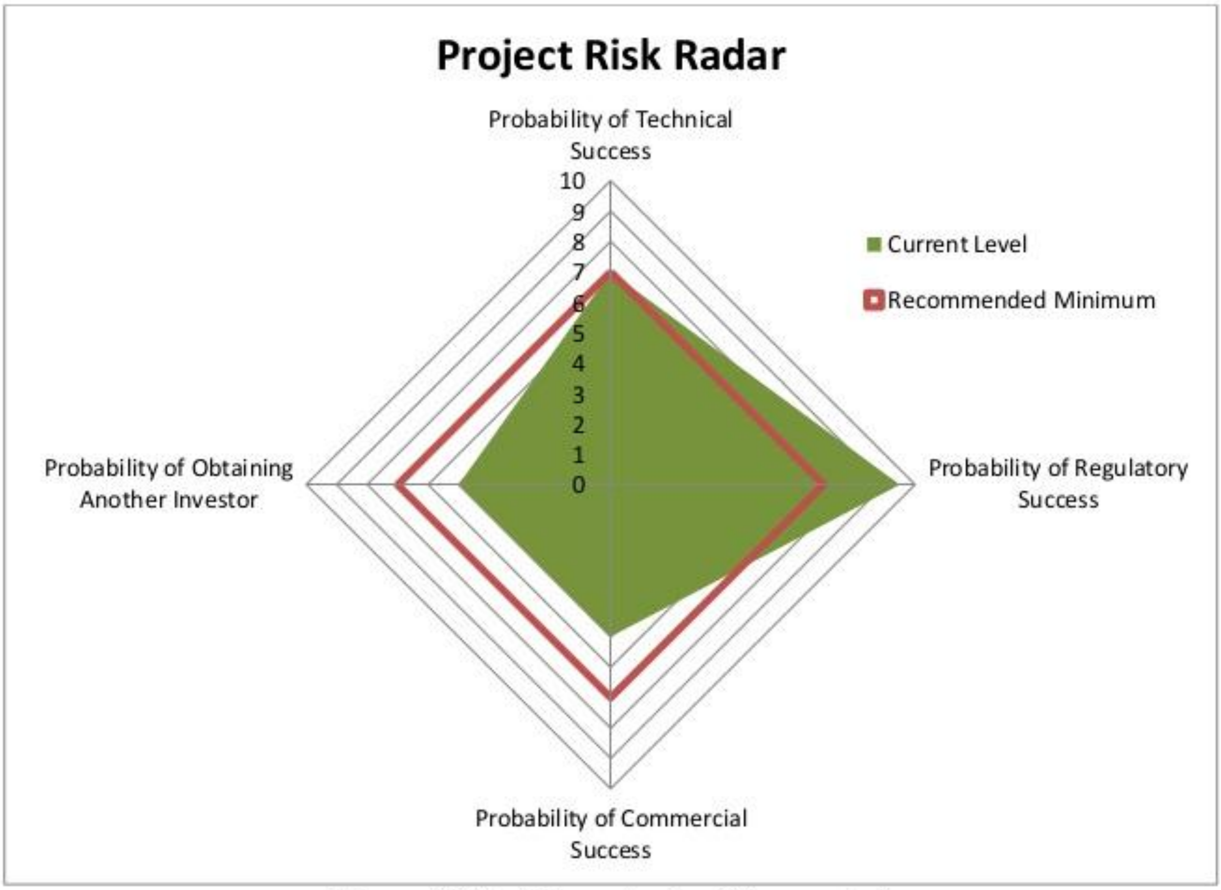

Figure 6) A risk analysis of the project

4.3.Impact of Delaying the Project

There is a risk of other automated asparagus growers being developed for green asparagus if RHL does not develop one soon. This could allow Lewis Farms to purchase automated harvesters for their own use, however the purchase price is likely to be high which would prevent expansion when harvesting asparagus for Californian growers.

If the project is delayed the profits once automated harvesters will also be delayed. These profits could be further impacted by other automated asparagus harvesters reaching the market sooner, reducing the demand on RHL's services.

This project currently assumes that another asparagus grower will be interested in investing in the development. If other options arise then there is a large risk of not being able to find other investors. This would lead to RHL requiring funding from non-asparagus growing investors, or RHL funding a lot more money themselves.

5. Marketing & Sales

RHL is offering a service rather than a product and the need for this service is very large; therefore trust and relationships must be developed.

5.1. Marketing Strategy

The first domestic customer is already established through their ownership of the Intellectual Property surrounding automated asparagus harvesting, Lewis Farms. There is a high chance of media attention surrounding the uptake of automated harvesting, and any other asparagus growers with a definite need for this service are likely to contact RHL. If there is not a large amount of media attention then this should be pursued.

Before the harvesters are performing well in New Zealand conditions, asparagus growers in California should be contacted. Through contacting Californian growers early relationships can begin to form, and if the Californian growers are given regular updates on the status of the harvester development then they will feel like they are a part of the project. This will also decrease the chance of overseeing important design factors that may be different for California compared to New Zealand.

Once RHL has become established as a trustworthy and reliable asparagus harvesting business then other markets can be explored.

5.2. Sales Strategy

There is an opportunity to sell automated asparagus harvesters once the system is performing well, however this could be detrimental to RHL's business.

The calculated price that asparagus growers with 40 hectares of asparagus will be willing to pay for an automated asparagus harvester with a 4 year payback period is $365,464.68, see table A.3. With an estimated cost of manufacturing automated asparagus harvesters of $150,000 there is money to be made through selling automated asparagus harvesters, however this will come at a cost as explained in the following points.

If harvesters are sold then there will be competitor's robotically harvesting green asparagus and taking business away from RHL.

As well as the above point there is a chance that the purchasers could copy the system and start selling similar products resulting in a decrease demand for RHL's harvesting services.

Another major factor is that if harvesters were sold then RHL would require a strong service team to solve any problems that arose with sold systems. Through having a dedicated service team automated harvesters operating for RHL would receive more fault fixes and the service team could be another source of income.

Due to the above points at this point in time **RHL should not sell automated asparagus harvesters**, instead they **should focus on offering a service** of harvesting asparagus for New Zealand and Californian asparagus growers.

6. Financial Projections

RHL is essentially a company spun-off from Lewis Farms so the financial projections have been performed in two ways:

1. What would be the finances if Lewis Farms and RHL were acting as a single company?
2. What would be the finances if RHL was operating independently?

The cost of automated asparagus harvesting has been calculated and compared to the 2011 manual harvesting costs, see figure 5. The manual harvesting costs for 2012 have not yet been finalised. The full calculations are shown in tables A.4 and A.5. These calculations assume that another investor is also interested in developing automated asparagus harvesters and shares the development costs equally with RHL.

Factor	Costs	
	Manual (2011)	Automated
Unit Harvesting Cost, ($/kg)	$ 1.40	$ 0.41
Yearly Harvesting Cost per Hectare, ($/ha)	$ 7,000.00	$ 2,025.00
Daily Harvesting Cost, ($/day)	$ 5,600.00	$ 1,620.00
Yearly Harvesting Cost, ($/year)	$ 560,000.00	$ 162,000.00

Table 7) A comparison of manual and automated asparagus harvesting running costs

6.1. Lewis Farms – RHL Integration

This method of calculating the finances determines what the accumulated costs of developing an automated asparagus harvester is, and what amount of money will be saved up to 10 years after the development first begins from Lewis Farms' point of view. Therefore it determines the:

- Current cost of harvesting asparagus.
- Forecast development costs and schedule.
- Forecast running costs of an automated harvester.
- Forecast profit to be made from international harvesting, see table A.8.

Required Funds per Investor										
Year	1	2	3	4	5	6	7	8	9	10
Money ($000)	133	273	422	456	299	45	-	-	-	-

Table 8) The accumulated required funds from Lewis Farms

Accumulated Cost Savings										
Year	1	2	3	4	5	6	7	8	9	10
Money ($000)	-	-	-	-	-	-	590	1,437	2,449	3,629

Table 9) The accumulated cost savings for Lewis Farms

Tables 8 and 9 show the full breakdown of the calculations using the following assumptions:

- The development of an automated asparagus harvester will cost $1.5 million spread evenly of 5 design iterations and 3 years.
- Funding will be available from the Ministry of Science and Innovation which will cover half of the development costs.
- Another investor will be interested in developing an automated asparagus harvester, and will share half of the development costs, with no other investors required.
- Each asparagus harvester will cost half of one design iteration to manufacture after development, thus $150,000.
- The interest rate on borrowed money is fixed at 6% p.a.
- In the first year after development one automated asparagus harvester will harvest asparagus from the land calculated in table A.5 with the remaining land harvested by hand, and in subsequent years all asparagus will be robotically harvested.
- Each year after development through an increase in reputation two extra automated harvesters will be built and fully utilised.
- The extra money required will come from a bank loan with the interest accumulating into this loan, until savings are made through automated harvesting which will be used to repay this loan.

6.2. RHL Independent

This method of calculating the finances determines what the accumulated costs of developing an automated asparagus harvester is, and what amount of money will be saved up to 10 years after the development first begins if RHL independently developed automated asparagus harvesters and contracted their services out. Therefore it determines the:

- Forecast development costs and schedule.
- Forecast running costs of an automated harvester.
- Forecast profit to be made from domestic and international harvesting, see tables A.8 and A.9.

Required Funds										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Money ($000)	133	273	422	456	299	45	-	-	-	-

Table 10) The accumulated required funds from RHL

Accumulated Profit										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Money ($000)	-	-	-	-	-	-	357	1,388	2,716	4,430

Table 11) The accumulated profits made by RHL

Tables 10 and 11 show the full breakdown of the calculations using the following assumptions:

- The development of an automated asparagus harvester will cost $1.5 million spread evenly of 5 design iterations and 3 years.
- Funding will be available from the Ministry of Science and Innovation which will cover half of the development costs.
- Another investor will be interested in developing an automated asparagus harvester, and will share half of the development costs, with no other investors required.
- Each asparagus harvester will cost half of one design iteration to manufacture after development, thus $150,000.
- The interest rate on borrowed money is fixed at 6% p.a.
- In the first year after development one automated asparagus harvester will harvest asparagus from the land calculated in table A.5.
- Each year after development through an increase in reputation two extra automated harvesters will be built and fully utilised.
- The extra money required will come from a bank loan with the interest accumulating into this loan, until profits are made through automated harvesting which will be used to repay this loan.

6.3. Net Present Value (NPV)

The net present value (NPV) for RHL being integrated with Lewis Farms' current operations as well as RHL operating independently have been calculated and **RHL should be run independently**. This is because the NPV for a range of discount rates is more favourable when RHL is run independently after a 10 year comparison, see figure 12. See figure 13 for the NPV over the first 10 years using a discount rate of 10%.

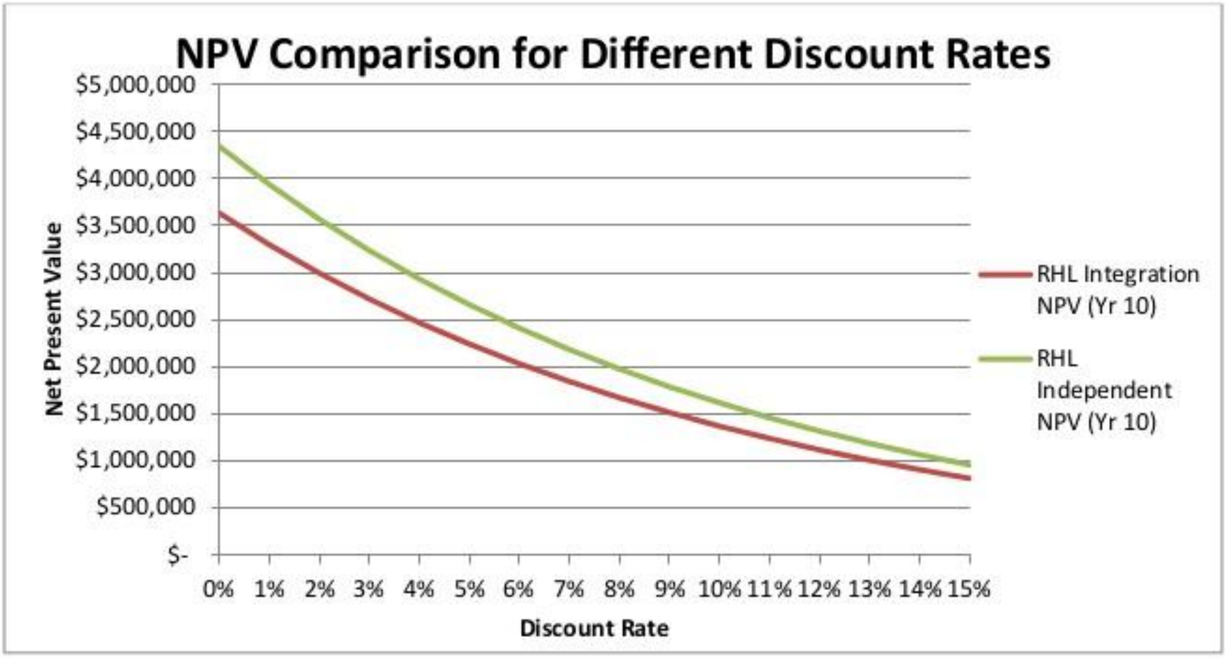

Figure 12) A comparison of the NPV for the two main business options across a range of discount rates

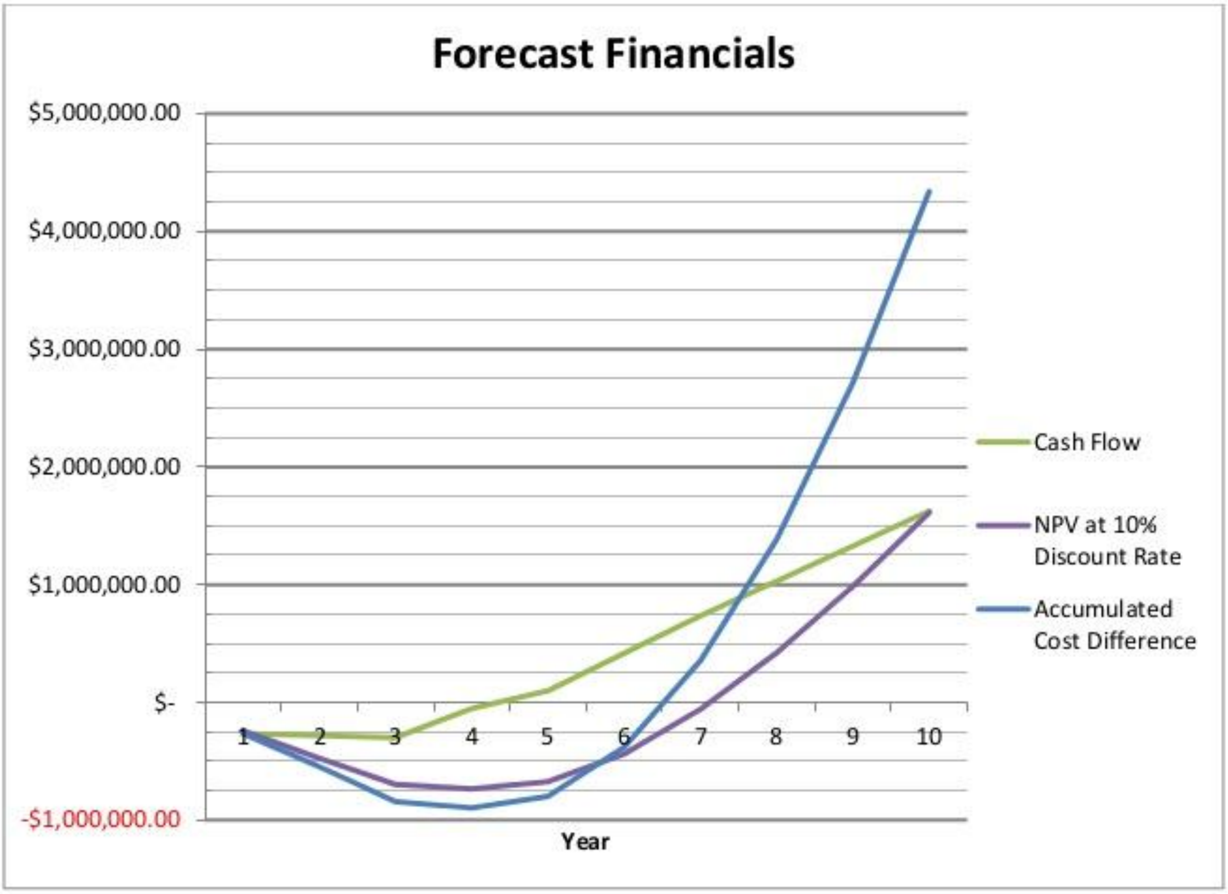

Figure 13) The financial predictions for RHL if it was run independently from Lewis Farms

6.4.Internal Rate of Return (IRR)

The internal rate of return (IRR) has been calculated, and after 10 years this is 33%, see table 14.

RHL Independent										
Year	1	2	3	4	5	6	7	8	9	10
Cash Flow ($000)	$265	$281	$298	$53	$99	$418	$736	$1,032	$1,328	$1,624
Present Value Factor	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386
NPV, at 10% ($000)	$240	$473	$697	$733	$671	$436	$58	$424	$987	$1,613
IRR							8%	20%	28%	33%

Table 14) The IRR for a break-even NPV over years 6 to 10

6.5.Financial Summary

Based on the two approaches described in sections 6.1 and 6.2 Lewis Farms should not integrate with RHL, instead RHL should independently develop automated asparagus harvesters, and contract out their services to all asparagus growers domestically and internationally including Lewis Farms. This will lead to a **NPV of $1.6 million in year 10 after development begins**.

7. Organisation & Management

RHL is to act as a limited liability company with the sharholders acting as the Board of Directors. This board will largely be the same as the board of Lewis Farms due their extensive knowledge and experience with asparagus, as well as the overlying ownership.

There will be a Chief Technical Officer (CTO) who is hired by the board and oversees the maintenance, upgrades, and fault-diagnosing for all of the automated harvesters, see figure 15. The CTO will be notifed about the majority of these faults and upgrades through the Harvester 1 Leader. Harvester 1 Leader will oversee the harvesting operations, managing the leaders of the other harvesters while also being in charge of a harvester and operator. This hierarchy provides a clear path of leadership and decision-making, without the upper level needing to micro-manage every step.

If any major problems arise then these will be passed up the heirarchy to the board, who will be able to make appropriate decisions.

With regards to the expansion plan of purchasing two new automated harvesters each year as envisaged in the financial projections, if more or less harvesters should be purchased then this decision will be made by the board based on the information received from the CTO and harvester leaders as well as other market information.

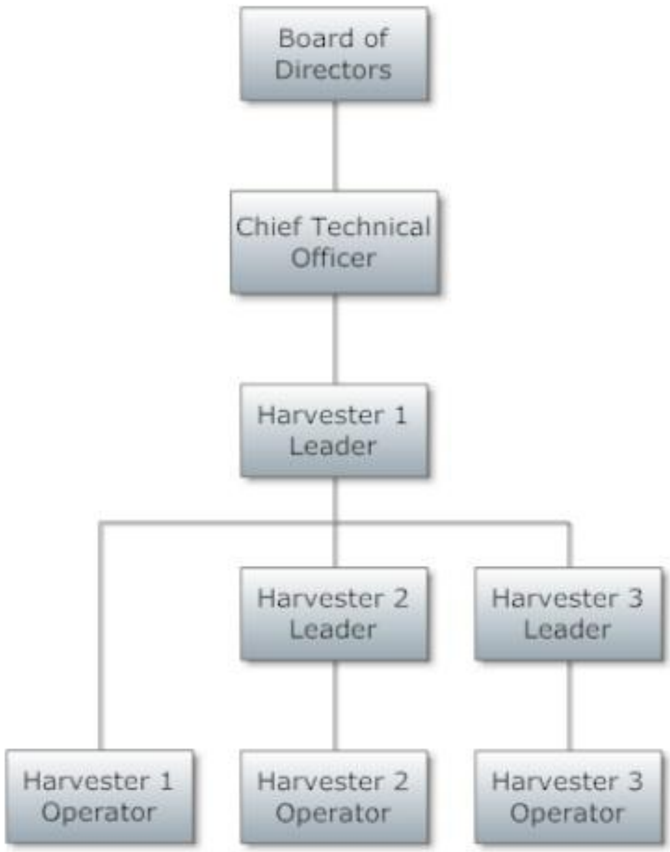

Figure 15) An organizational chart of RHL

8. Assumptions

Several assumptions have already been made in sections 6.1 and 6.2 with regards to the financial predictions that have been made, and these are:

- The development of an automated asparagus harvester will cost $1.5 million spread evenly of 5 design iterations and 3 years.
- Funding will be available from the Ministry of Science and Innovation which will cover half of the development costs.
- Another investor will be interested in developing an automated asparagus harvester, and will contribute half of the development costs, with no other investors required.
- Each asparagus harvester will cost half of one design iteration to manufacture after development, thus $150,000.
- The interest rate on borrowed money is fixed at 6% p.a.
- In the first year after development one automated asparagus harvester will harvest asparagus from the land calculated in table A.5.
- Each year after development through an increase in reputation two extra automated harvesters will be built and fully utilised.
- The extra money required will come from a bank loan with the interest accumulating into this loan, until profits are made through automated harvesting which will be used to repay this loan.

Other assumptions have been made in the creation of this business plan which are:

- There will be a guaranteed demand for the services of RHL due to the large amount of value it would add to an asparagus growers business.
- The barriers to harvesting asparagus overseas will be very small.
- The way green asparagus is grown is not going to change dramatically.
- No competitors are going to develop automated asparagus harvesters in the short to medium term and reduce the demand on RHL's services.

9. Schedule

The schedule depends entirely on Lewis Farms' current and planned business activities, therefore a start year has not yet been assigned. Once a start year has been set the schedule will follow the schedule outlined in table 16.

The accumulated required funds are outlined in table 9, and the accumulated profits are outlined in table 10. These numbers outline a break-even point of year 7 and an IRR of 33% after 10 years. Table A.7 shows where these numbers arise, and that a positive cash flow will be reached in year 5.

Year	Plan
1	Automated asparagus harvester development.
2	
3	
4	Use one machine for an asparagus season both in NZ and California while upgrading it and fixing problems that arise.
5	Build two extra machines, so 3 machines are harvesting NZ and California asparagus.
6	Build two extra machines, so 5 machines are harvesting NZ and California asparagus.
7	Build two extra machines, so 7 machines are harvesting NZ and California asparagus.
8	Build two extra machines, so 9 machines are harvesting NZ and California asparagus.
9	Build two extra machines, so 11 machines are harvesting NZ and California asparagus.
10	Build two extra machines, so 13 machines are harvesting NZ and California asparagus.

Table 16) The schedule for RHL

A. Appendices

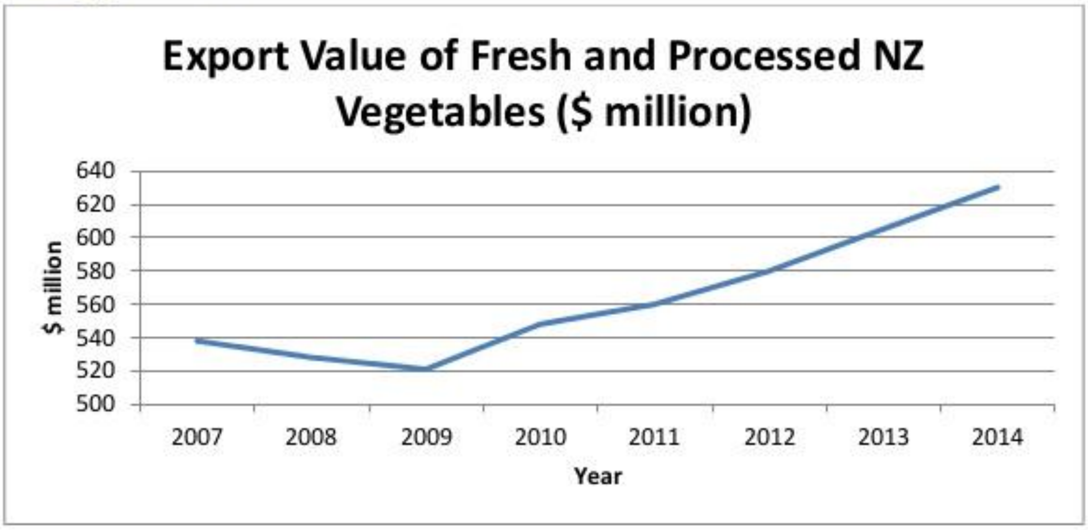

Figure A.1) The actual and forecast export value of fresh and process vegetables as of 2010[5]

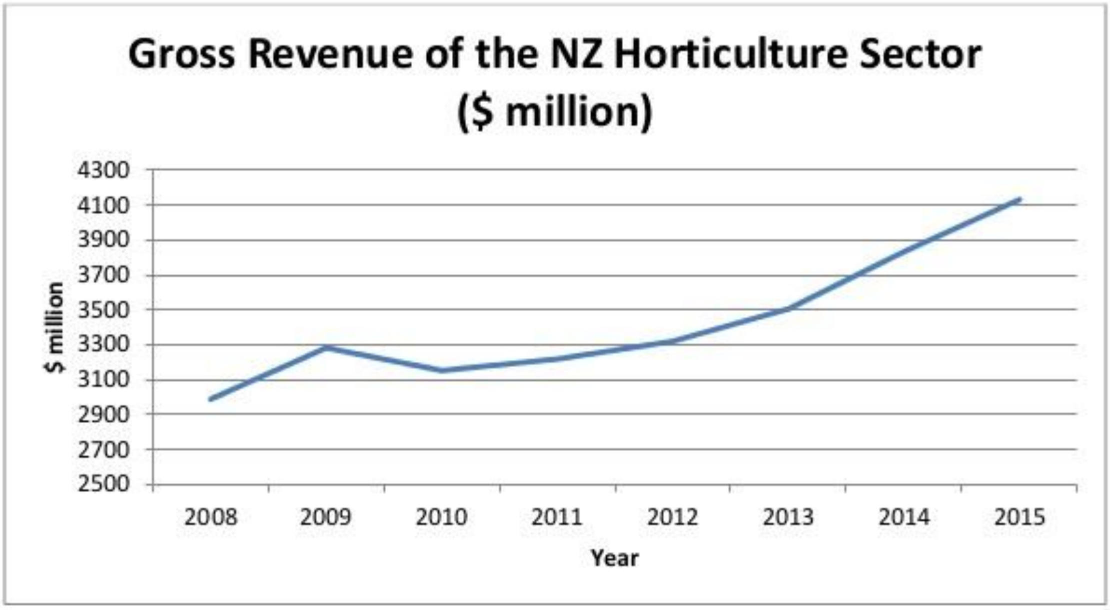

Figure A.2) The actual and forecast gross revenue for the NZ horticulture sector as of 2011

[5] Ministry of Agriculture and Forestry, *Situation and Outlook for New Zealand Agriculture and Forestry*, 2011.

Year	1	2	3	4	5	6
Asparagus Area (ha)	40	40	40	40	40	40
Asparagus Density (kg/ha)	5000	5000	5000	5000	5000	5000
Manual Harvesting Unit Cost ($/kg)	$1	$1	$1	$1	$1	$1
Total Manual Harvesting Cost ($)	$280,000	$280,000	$280,000	$280,000	$280,000	$280,000
Harvesters Required	2	2	2	2	2	2
Automated Harvester Purchase Cost ($)	$730,929	$ -	$ -	$ -	$ -	$ -
Asparagus Area (ha)	40	40	40	40	40	40
Asparagus Density (kg/ha)	5000	5000	5000	5000	5000	5000
Automated Harvesting Unit Cost ($/kg)	$0	$0	$0	$0	$0	$0
Automated Harvesting Costs ($)	$81,000	$81,000	$81,000	$81,000	$81,000	$81,000
Total Automated Harvesting And Purchase Costs ($)	$811,929	$81,000	$81,000	$81,000	$81,000	$81,000
Yearly Difference in Costs ($)	- $531,929	$199,000	$199,000	$199,000	$199,000	$199,000
Accumulated Difference in Costs ($)	- $531,929	- $364,845	- $187,736	$0	$199,000	$398,000
Interest on Accumulated Costs, at 6% p.a. ($)	-$31,916	-$21,891	-$11,264	$ -	$ -	$ -
Required Additional Funds	- $563,845	- $386,736	- $199,000	$ -	$ -	$ -
Accumulated Harvesting Cost Savings	$ -	$ -	$ -	$0	$199,000	$398,000

Table A.3) The payback plan for asparagus growers with a 4 year payback period

Manual Harvesting Costs	
Manual Harvesting Cost 2011, ($/kg)	$1.40
Paddock Growth 2011, (kg/ha)	5000
Yearly Manual Harvesting Cost per Area, ($/ha)	$7,000
Asparagus Planted (ha)	80
Total Manual Harvesting Cost, 2011 ($)	*$560,000*
Number of Days per Season	100
Daily Manual Harvesting Cost	$5,600

Table A.4) Manual harvesting costs for Lewis Farms based on 2011 data

Automated Harvesting Costs	
Asparagus Planted (ha)	80
Asparagus Rows per Area, (km/ha)	6.06
Length of Asparagus Rows (km)	485
Single Row Automated Harvester Speed, (km/h)	3
Number of Rows Automatedly Harvested per Pass	3
Required Automated Harvesting Time per Day (hrs/day)	53.867
Available Working Time per Day per Machine (hrs/day)	18
Number of Automated Machines Initially Required	2.99
Area Harvested per Automated Machine (ha/day)	26.73267
Labour Rate per Automated Harvester, ($/hr)	$20
Running Cost per Automated Harvester, ($/hr)	$10
Total Costs per Automated Harvester, ($/hr)	$30
Total Costs per Automated Harvester, ($/day)	$540
Number of Days per Season (days/season)	100
Yearly Automated Harvesting Operation Costs, 3 machines ($/season)	*$162,000*
Yearly Automated Harvesting Cost per Area, ($/ha)	$2,025
Daily Automated Harvesting Cost ($)	$1,620
Paddock Growth 2011, (kgs/ha)	5000
Automated Harvesting Cost per kg ($/kg)	$0.41

Table A.5) Predicted automated harvesting costs

Year	1	2	3	4	5	6	7	8	9	10
Asparagus Area (ha)	80	80	80	80	80	80	80	80	80	80
Asparagus Density (kg/ha)	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
($/kg)	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40	$1.40
Total Harvesting Cost ($)	$560,000.00	$560,000.00	$560,000.00	$560,000.00	$560,000.00	$560,000.00	$560,000.00	$560,000.00	$560,000.00	$560,000.00
Automated Harvester Development Cost ($)	$125,000.00	$125,000.00	$125,000.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Harvesters Required	0	0	0	1	3	5	7	9	11	13
Automated Harvester Purchase Cost ($)	$ -	$ -	$ -	$150,000.00	$300,000.00	$300,000.00	$300,000.00	$300,000.00	$300,000.00	$300,000.00
Asparagus Area (ha)	80	80	80	80	80	80	80	80	80	80
Asparagus Density (kg/ha)	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
Manual Harvesting Unit Cost	$1.40	$1.40	$1.40	$1.40	$ -	$ -	$ -	$ -	$ -	$ -
Automated Harvesting Unit Cost ($/kg)	$ -	$ -	$ -	$0.41	$0.41	$0.41	$0.41	$0.41	$0.41	$0.41
Total Domestic Harvesting and Development Costs ($)	$685,000.00	$685,000.00	$685,000.00	$577,004.95	$462,000.00	$462,000.00	$462,000.00	$462,000.00	$462,000.00	$462,000.00
Money from International Harvesting ($)	$ -	$ -	$ -	$ -	$249,490.10	$415,816.83	$582,143.56	$748,470.30	$914,797.03	$1,081,123.76
Yearly Difference in Costs ($)	-$125,000.00	-$125,000.00	-$125,000.00	-$17,004.95	$347,490.10	$513,816.83	$680,143.56	$846,470.30	$1,012,797.03	$1,179,123.76
Accumulated Difference in Costs	-$125,000.00	-$257,500.00	-$397,950.00	-$438,831.95	-$117,671.77	$389,084.76	$1,069,228.32	$1,915,698.62	$2,928,495.65	$4,107,619.41
Interest on Accumulated Costs ($)	-$7,500.00	-$15,450.00	-$23,877.00	-$26,329.92	-$7,060.31	$ -	$ -	$ -	$ -	$ -
Required Additional Funds	-$132,500.00	-$272,950.00	-$421,827.00	-$465,161.87	-$124,732.07	$ -	$ -	$ -	$ -	$ -
Savings	$ -	$ -	$ -	$ -	$ -	$389,084.76	$1,069,228.32	$1,915,698.62	$2,928,495.65	$4,107,619.41

Table A.6) The finances if Lewis Farms integrated with RHL

Year	1	2	3	4	5	6	7	8	9	10
Automated Harvester Development Cost ($)	$250,000.00	$250,000.00	$250,000.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Harvesters Wanted	0	0	0	1	3	5	7	9	11	13
Automated Harvester Purchase Cost ($)	$ -	$ -	$ -	$150,000.00	$300,000.00	$300,000.00	$300,000.00	$300,000.00	$300,000.00	$300,000.00
Total Development and Purchase Costs ($)	$250,000.00	$250,000.00	$250,000.00	$150,000.00	$300,000.00	$300,000.00	$300,000.00	$300,000.00	$300,000.00	$300,000.00
Number of Automated Harvesters Sold	0	0	0	0	0	0	0	0	0	0
Money From Selling Machines ($)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Money from Domestic Harvesting ($)	$ -	$ -	$ -	$64,811.88	$194,435.64	$324,059.41	$453,683.17	$583,306.93	$712,930.69	$842,554.46
Money from International Harvesting ($)	$ -	$ -	$ -	$83,163.37	$249,490.10	$415,816.83	$582,143.56	$748,470.30	$914,797.03	$1,081,123.76
Yearly Difference in Costs ($)	-$250,000.00	-$250,000.00	-$250,000.00	-$2,024.75	$143,925.74	$439,876.24	$735,826.73	$1,031,777.23	$1,327,727.72	$1,623,678.22
Accumulated Difference in Costs ($)	-$250,000.00	-$515,000.00	-$795,900.00	-$845,678.75	-$752,493.74	-$357,767.12	$356,593.58	$1,388,370.81	$2,716,098.53	$4,339,776.75
Interest on Accumulated Costs ($)	-$15,000.00	-$30,900.00	-$47,754.00	-$50,740.73	-$45,149.62	-$21,466.03	$ -	$ -	$ -	$ -
Total Accumulated Difference in Costs ($)	-$265,000.00	-$545,900.00	-$843,654.00	-$896,419.48	-$797,643.36	-$379,233.15	$356,593.58	$1,388,370.81	$2,716,098.53	$4,339,776.75

Table A.7) The finances if RHL was independent

International Harvesting Profit	
Daily Asparagus Harvested (spears/harvester/day)	53,465
Number of Days per US Asparagus Season (days)	150
Average Spears per kg (spears/kg)	45
Seasonal US Asparagus Harvested (kg/harvester)	178,218
US Piecewise Asparagus Harvesting Rate, minimum (US$/kg)	$0.80
USD to NZD conversion rate, as at 19 December 2012	1.19
Seasonal Revenue per Automated Harvester	$169,663.37
Seasonal Running Costs per Automated Harvester ($/harvester)	$81,000.00
Number of People per Automated Harvester	2.5
Flights Costs per Automated Harvester Operator	$2,000.00
Freight Costs per Automated Harvester ($/harvester)	$500
Total Seasonal Costs per Automated Harvester ($/harvester)	$86,500
Total Profit per Automated Harvester ($/harvester)	$83,163.37

Table A.8) The profit to be made from international harvesting

Domestic Harvesting Profit	
Daily Asparagus Harvested (spears/harvester/day)	53,465
Number of Days per NZ Asparagus Season (days)	100
Average Spears per kg (spears/kg)	45
Seasonal NZ Asparagus Harvested (kg/harvester)	118,812
US Piecewise Asparagus Harvesting Rate, minimum (US$/kg)	$1.00
Seasonal Revenue per Automated Harvester	$118,811.88
Seasonal Running Costs per Automated Harvester ($/harvester)	$54,000.00
Total Profit per Automated Harvester ($/harvester)	$64,811.88

Table A.9) The profit to be made from domestic harvesting